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REPORT OF INVESTIGATIONS—NO. 62

MISSISSIPPIAN BORDER OF EASTERN INTERIOR BASIN

BY

J. MARVIN WELLER AND A. H. SUTTON

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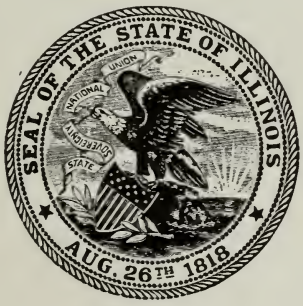

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Topographic Mapping in Cooperation with the United States Geological Survey.

September 15, 1939

Volume 24 Number 5

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MAY, 1940

MISSISSIPPIAN BORDER OF EASTERN INTERIOR BASIN[1]

J. MARVIN WELLER[2] AND A. H. SUTTON[3]
Urbana, Illinois

ABSTRACT

The Mississippian system along the borders of the Eastern Interior basin has been studied in considerable detail during the last 30 years but the results of most of this work have not yet been published. This paper briefly discusses the stratigraphy, paleontology, sedimentation, and structure and lists petroleum-bearing beds of the Mississippian system in Illinois, Indiana, western Kentucky, eastern Missouri, and southeastern Iowa as based on the published and unpublished investigations of more than 25 geologists and their numerous assistants, who worked mainly under the auspices of the various State geological surveys. Accompanying maps show the areal geology from Mercer County, Illinois, to Putnam County, Indiana, and include more than fifty 15-minute quadrangles which have been studied in detail.

INTRODUCTION

In 1913 a coöperative plan of study and correlation of the Mississippian formations of the upper Mississippi Valley was developed by the several State geological surveys of the area and the United States Geological Survey. This work was placed under the supervision of Professor Stuart Weller, who had been actively engaged in a study of the Mississippian faunas for more than 15 years and who had begun the detailed mapping of the upper Mississippian strata in southern Illinois in 1911.

As results of this coöperative investigation there have appeared two important volumes on the lower Mississippian of Iowa and Missouri, respectively (67, 41).[4] Other volumes on the Mississippian formations of western Kentucky (7) and the lower Mississippian of

[1] Read before the Association at Oklahoma City, March 24, 1939. Manuscript received, October 2, 1939. Published by permission of the chief, Illinois State Geological Survey; the director, Kentucky Geological Survey; the State geologist of Indiana; and the director, Missouri Geological Survey.

[2] Illinois State Geological Survey.

[3] University of Illinois.

[4] Numbers in parentheses refer to bibliography at end of article.

			STANDARD SECTION	SW ILLINOIS	SE ILL & W KY	W CENTRAL KY	SW INDIANA
MISSISSIPPIAN SYSTEM	CHESTER SERIES	ELVIRA GROUP	KINKAID LS.	KINKAID LS.	KINKAID LS	LEITCHFIELD FM	NEGLI CREEK LS
			DEGONIA SS.	DEGONIA SS	DEGONIA SS		MT. PLEASANT SS.
			CLORE SH & LS	CLORE SH & LS	CLORE SH & LS.		GENNET CREEK SH
			PALESTINE SS	PALESTINE SS	PALESTINE SS		BRISTOW SS.
			MENARD LS	MENARD LS	MENARD LS		SIBERIA LS.
			WALTERSBURG SS	BALDWIN FM	WALTERSBURG SS.		WICKCLIFF SS.
			VIENNA LS.		VIENNA LS		UNNAMED SH.
			TAR SPRINGS SS.		TAR SPRINGS SS		TAR SPRINGS SS.
		HOMBERG GROUP	GLEN DEAN LS	OKAW LS	GLEN DEAN LS	GLEN DEAN LS	GLEN DEAN LS.
			HARDINSBURG SS		HARDINSBURG SS	HARDINSBURG SS	HARDINSBURG SS
			GOLCONDA LS.		GOLCONDA SH & LS	GOLCONDA LS	GOLCONDA LS
							INDIAN CREEK SH.
			CYPRESS SS	RUMA FM.	CYPRESS SS	CYPRESS SS	CYPRESS SS.
		NEW DESIGN GROUP	PAINT CREEK SH & LS	PAINT CREEK SH	PAINT CREEK SH & LS	GIRKIN LS	BEECH CREEK LS
							ELWREN SS
							REELSVILLE LS
			BETHEL SS	YANKEETOWN CHERT	BETHEL SS		SAMPLE SS
			RENAULT LS & SH.	RENAULT FM	RENAULT LS & SH		BEAVER BEND LS
							MOORETOWN LS
							PAOLI LS
			AUX VASES SS	AUX VASES SS			
	IOWA SERIES	MERAMEC GROUP	STE. GENEVIEVE LS	HOFFNER MEMBER			
				LEVIAS LS	LEVIAS LS.	STE GENEVIEVE LS	STE GENEVIEVE LS.
				ROSICLARE SS	ROSICLARE SS		
				FREDONIA LS	FREDONIA LS		
			ST LOUIS LS	ST LOUIS LS	ST LOUIS LS.	ST. LOUIS LS	ST LOUIS LS
			SALEM LS.	SALEM LS	WARSAW LS.	WARSAW LS	SALEM LS
			WARSAW FM	WARSAW LS			HARRODSBURG LS
		OSAGE GROUP	KEOKUK LS.	OSAGE FM	OSAGE FM	EDWARDSVILLE FM	EDWARDSVILLE FM.
			BURLINGTON LS.			CARWOOD FM	CARWOOD FM
			FERN GLEN LS & SH.			LOCUST POINT FM	LOCUST POINT FM
						NEW PROVIDENCE SH	NEW PROVIDENCE SH
		KINDERHOOK GROUP	CHOUTEAU LS				ROCKFORD LS
			HANNIBAL SH & SS	SPRINGVILLE SH			
			LOUISIANA LS				
			GRASSY-SAVERTON SH				
				MOUNTAIN GLEN SH	CHATTANOOGA SH PART	NEW ALBANY SH PART	NEW ALBANY SH PART

FIG. 1.—Correlation chart of Mississippian formations exposed on borders of Eastern Interior basin. Ls., limestone; ss., sandstone; sh., shale; fm., formation.

Missouri (4) have also been published, but these were not a part of the coöperative program. All of these reports were based on reconnaissance studies.

Professor Weller's own investigations, which continued without interruption until his death in 1927, as well as the work of others under his supervision, involved the detailed mapping of the Mississippian formations in southwestern Missouri, across southern Illinois, and well into western Kentucky. Although reports on detailed studies in certain restricted areas have been issued (32, 56, 68, 87, 88, 90, 94, 96), publication of the results of most of this work was deferred in anticipation of a series of monographs long planned by Professor Weller but hardly begun before his death.

After 1927, Mississippian studies in western Kentucky were continued under the direction of Sutton, and by 1932 mapping of the formations was nearly completed throughout the zone of outcrop from St. Louis, Missouri, to Louisville, Kentucky.

In western Illinois north of St. Louis, detailed studies of the Mississippian system have been made in connection with a number of separate quadrangle surveys, but the deep covering of glacial drift and uncertainty regarding the exact position of several formational boundaries make it impossible as yet to delineate accurately the areal geology throughout this region.

The belt of Mississippian outcrop in southwestern Indiana has been studied mainly in reconnaissance because of the lack of topographic maps, but the recent work of C. A. Malott and P. B. Stockdale has added much to the knowledge of this region.

As detailed information concerning the Mississippian system and particularly its upper division, the Chester series, has accumulated, a growing need has been felt for a report or series of reports describing its stratigraphy and structure. This paper is presented as a preliminary report outlining in a unified manner the latest and most complete information available concerning the Mississippian system on the borders of the Eastern Interior basin. It embodies data obtained by more than twenty-five geologists and their numerous assistants working mainly under the auspices of the various State geological surveys. Permission to use much unpublished information and many manuscript maps has been granted by the chief of the Illinois State Geological Survey, the director of the Kentucky Geological Survey, the State geologist of Indiana, and the director of the Missouri Bureau of Geology and Mines.

Professor Weller's extensive and detailed studies, with which the writers are intimately acquainted, have provided the foundation of

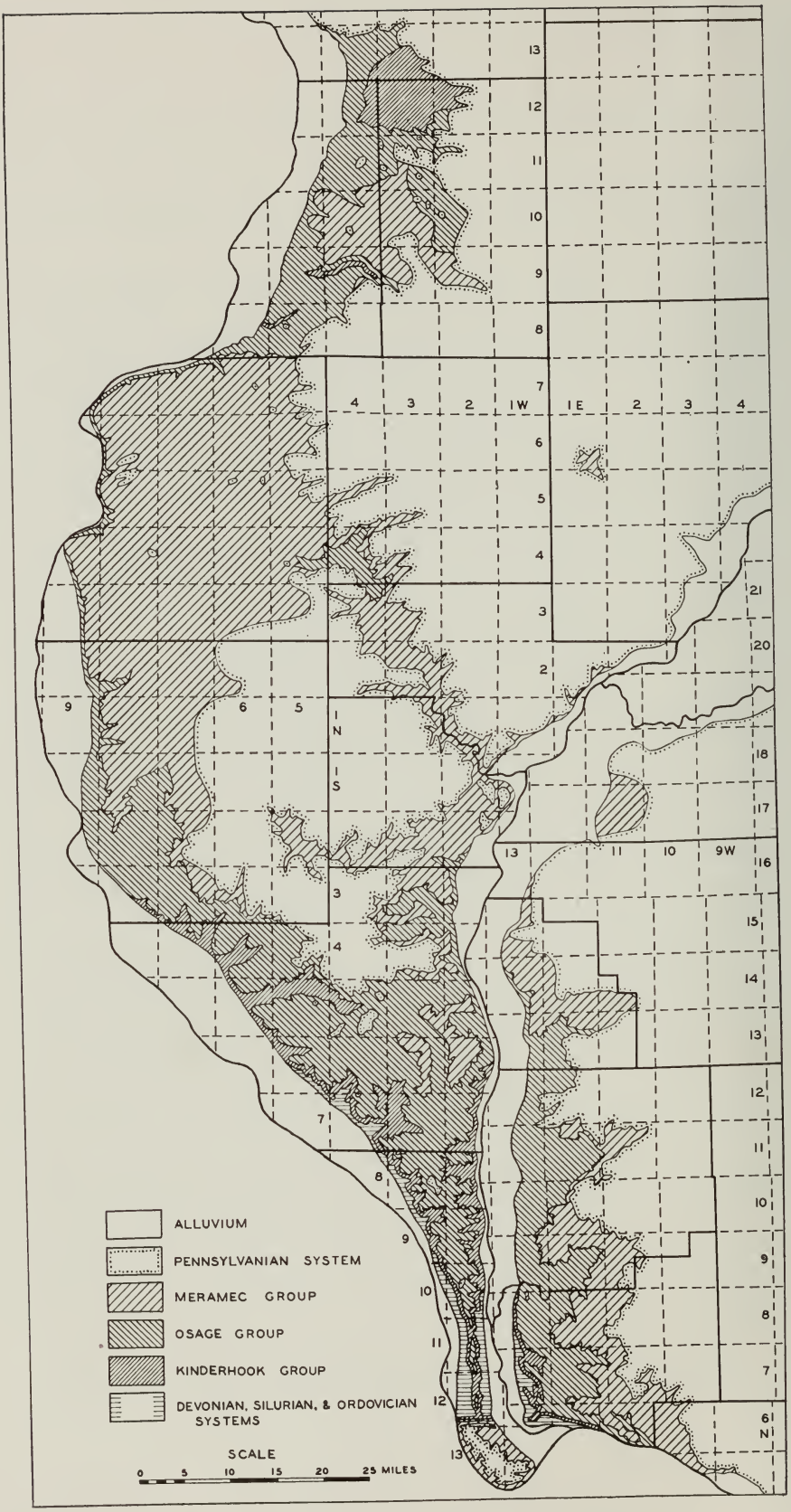

FIG. 2.—Map showing distribution of outcropping Mississippian rocks in western Illinois from Madison County to Mercer County. (After "Geologic Map of Illinois," compiled by J. Marvin Weller with assistance of other members of Survey staff, *Illinois State Geological Survey*, July 1, 1939.)

the following stratigraphic and paleontologic discussions and much of the information contained therein. C. A. Malott has generously placed at the writers' disposal unpublished information concerning the Chester series in Indiana. Others whose unpublished work in Illinois and Kentucky has contributed to the completeness of this paper are: A. H. Bell, C. C. Branson, B. B. Cox, J. A. Culbertson, George E. Ekblaw, R. F. Flint, J. R. Griffin, F. F. Krey, S. M. Mayfield, W. W. Ruby, T. E. Savage, A. H. Sutton, J. R. VanPelt, Jr., and J. M. Weller.

The map showing the distribution of the Mississippian rocks in western Illinois (Fig. 2) is copied from a new geological map of Illinois compiled by J. M. Weller.

The areal maps (Figs. 4–9b) accompanying this paper are copied from geological maps prepared by various men on standard quadrangle topographic maps (scale, 1 inch equals 1 mile) on most of which each formation is indicated separately. Reduction in scale, however, has made it necessary to combine the different formations into (1) upper Chester, (2) middle Chester, (3) lower Chester, (4) Meramec, and (5) Osage groups. The Kinderhook group is not shown because it is either absent or too thin, or because it is not differentiated from the "Devonian" black shale.

An unpublished generalized map of the three main divisions of the Chester series in Indiana, as prepared by C. A. Malott, has been used in combination with the geological map of the state to produce the areal map of the same Mississippian groups in Indiana (Fig. 10).

EASTERN INTERIOR BASIN

The Eastern Interior basin is an irregularly subcircular structural depression 250 to 300 miles in diameter, occupying the greater part of Illinois, southwestern Indiana, and western Kentucky and attaining in southeastern Illinois a maximum structural depth of more than 5,000 feet below its borders. It is bounded on the northeast by the Kankakee arch, on the east by the Lexington dome, on the southeast by the Nashville dome, on the south by the Mississippi embayment, on the southwest by the Ozark dome, and on the northwest by the Mississippi arch. The structure of this arch, which separates the Eastern Interior and Western Interior basins, is not known in detail. It appears to be a broad, more or less irregular saddle connecting the northeastern extremity of the Ozark uplift with the southwestern slope of the Wisconsin arch. Its axis is probably located farther west and trends more nearly northeast and southwest than is shown on

recent maps.[5] The Mississippi arch is evidently a very old structure which influenced sedimentation at least from the Ordovician through Pennsylvanian time, as many formations thin notably upon it.

The major structural features within the Eastern Interior basin are the asymmetrical LaSalle anticline which extends southeastward across Illinois from near Dixon to Wabash River; the Shawneetown-Rough Creek zone of faulting which extends from Saline County, Illinois, to Hart County, Kentucky; the complicated fault zone that extends from Union County, Illinois, to Ste. Genevieve County, Missouri; the Hicks dome in Hardin County, Illinois, and the associated faulted area in neighboring parts of Illinois and Kentucky; the Valmeyer anticline in Monroe County, Illinois, and Jefferson County, Missouri; the Waterloo-Dupo anticline in Monroe and St. Clair counties, Illinois, and St. Louis County, Missouri; the Cap-au-Gres fault and flexure zone which extends from Jersey County, Illinois, through Lincoln County, Missouri; the Pittsfield anticline in Pike County, Illinois; the Lincoln anticline in Lincoln and Pike counties, Missouri; and the Du Quoin "anticline" in southwestern Illinois. Minor faults and folds are common elsewhere in the basin.

Throughout at least the latter part of the Paleozoic era the Eastern Interior basin was a dominantly negative area whose form was determined by the passively positive Ozark dome, Wisconsin and Lake Superior highlands, and Cincinnati arch. The western, northern, and eastern limits of the basin were determined long before the beginning of the Mississippian period, but the southern border was produced by post-Paleozoic pre-late Cretaceous deformation.

MISSISSIPPIAN SYSTEM

General distribution.—The Mississippian system underlies approximately 70,000 square miles in Illinois, Indiana, and western Kentucky and crops out in a belt 750 miles long around the western, southern and eastern borders of the Eastern Interior basin. It attains a maximum thickness of nearly 3,000 feet in southern Illinois and western Kentucky and thins northward because in that direction not only do its constituent formations thin but they are also bevelled by post-Mississippian pre-Pennsylvanian erosion.

Economic importance.—Nearly half of the petroleum produced from the old fields in this region and most of that produced from the new Illinois fields have come from Mississippian formations. The limestone strata are used extensively for lime, crushed rock, riprap, rock

[5] See J. V. Howell, "Tectonic Map of Central United States," *Kansas Geological Society* (1931), and "The Mississippi River Arch," *Kansas Geological Society, Ninth Annual Field Conference Guide-Book* (1935), pp. 386–89.

wool, and similar products, and certain strata are quarried for dimension stone in the Bedford, Indiana, district which is the greatest center of the building-stone industry in the United States. The fluorspar in the famous southern Illinois and western Kentucky district and some of the natural rock asphalt in west-central Kentucky occur in Mississippian rocks.

Classification.—A relatively recent discussion of the classification of the Mississippian strata in the upper Mississippi and lower Ohio valleys has already been published (16, pp. 475–86). The classification which has been standard in the most recent publications of the Illinois State Geological Survey is used in this report and accordingly the Mississippian system is subdivided into the Iowa series below, consisting of the Kinderhook, Osage, and Meramec groups, and the Chester series above.

For several years, however, the writers have believed that the stratigraphic and faunal relations existing within the Mississippian system are more in accord with a three-fold subdivision and that the Kinderhook should be raised in rank from a group to a series and that another, the Valmeyer series,[6] consisting of the Osage and Meramec groups, should be recognized. The system would thus be separated into beds of lower, middle, and upper Mississippian age in a manner similar to most of the other Paleozoic systems. The reasons follow.

1. A careful consideration of the successive Mississippian faunas shows that, although the Chester and Iowa series consist of approximately equal thicknesses of strata, the Iowa contains the record of a much greater life development and so presumably represents much the greater part of Mississippian time. A considerable array of invertebrate species range from the bottom to the top of the Chester series but only a single rather elastic species, *Linoproductus ovatus*, passes from the Kinderhook through the Osage and into the Meramec group.

2. The Chester series with its preponderantly clastic strata is in strong contrast to the Osage and Meramec groups in the type area where they are represented largely by limestone, and on this basis the

[6] This three-fold division of the Mississippian system and the name Valmeyer, from a town in southwestern Illinois, were first proposed by the writers in a manuscript on the Mississippian formations of the Eastern Interior basin written in 1930–31. Shortly afterward, R. C. Moore submitted for their comment part of the manuscript for a textbook in which he was also proposing an identical division. After consultation, Moore accepted the name Valmeyer for the middle series and this was first published in his book (42, pp. 261–64). This classification has been used in a number of subsequent publications but objections to it have been expressed (34, pp. 1158–59). Recently Moore has abandoned this classification in favor of another three-fold classification consisting in ascending order of the Waverly, Meramec, and Chester series (44, p. 671), but the writers believe that this subdivision is not in harmony with the stratigraphic and faunal characters of the Mississippian system in the central United States.

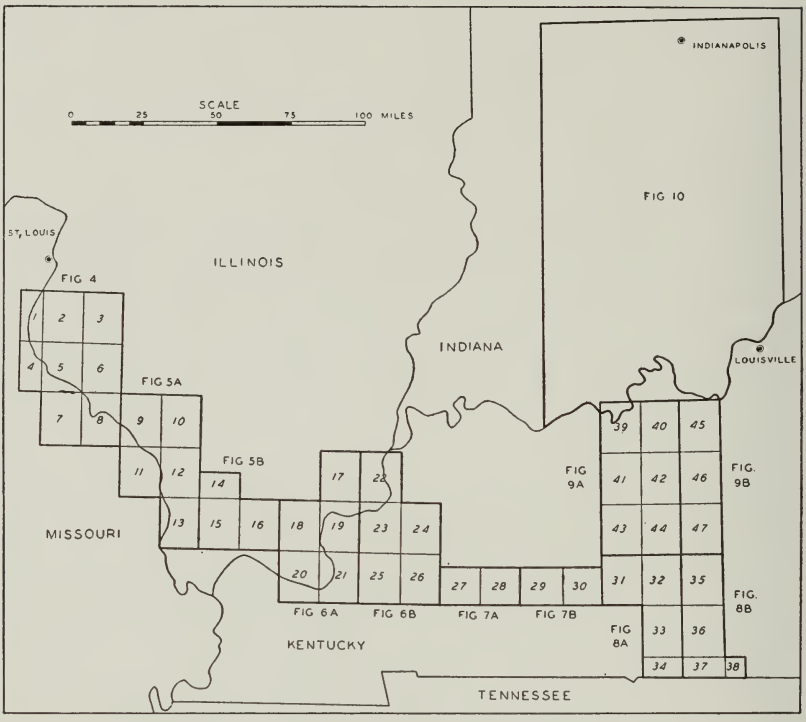

Fig. 3.—Index map showing areas covered in Figs. 4–10. Numbers within quadrangles serve as index to following list of names, wherewith are also given names of geologists who mapped Mississippian strata, dates of mapping, and character of mapping (detail, semi-detail, and reconnaissance). Asterisk (*) indicates unpublished maps.

(1) *Kimmswick Quadrangle* (Illinois portion), Stuart Weller, 1911, detail
(2) *Waterloo Quadrangle*, Stuart Weller, 1911, detail
(3) *New Athens Quadrangle*, Stuart Weller, detail
(4) *Crystal City Quadrangle* (Illinois portion), Stuart Weller, 1913, detail
(Ste. Genevieve County, Missouri portion), Stuart Weller, 1914, detail
(5) *Renault Quadrangle* (Illinois portion), Stuart Weller, 1912, detail
(Missouri portion), Stuart Weller, 1914, detail
(6) *Baldwin Quadrangle*, Stuart Weller, 1913, detail
(7) *Weingarten Quadrangle*, Stuart Weller, 1914, detail
(8) *Chester Quadrangle* (Illinois portion), Stuart Weller, 1913, detail
(Missouri portion), Stuart Weller, 1914, detail
(9) *Campbell Hill Quadrangle*, J. M. Weller, 1919, detail
(10) *Murphysboro Quadrangle*, E. W. Shaw, 1909, semi-detail
(11) *Altenburg Quadrangle* (Missouri portion), R. F. Flint, 1924, detail*
(12) *Alto Pass Quadrangle*, F. F. Krey, 1923, G. E. Ekblaw, 1924, detail* (incomplete)
(13) *Jonesboro Quadrangle*, T. E. Savage, 1919, detail*
(14) *Carbondale Quadrangle*, J. E. Lamar, 1922, 1923, detail
(15) *Dongola Quadrangle*, F. F. Krey, 1921, detail
(16) *Vienna Quadrangle*, Stuart Weller, 1918, 1919, detail
(17) *Equality Quadrangle*, Charles Butts, 1917, 1918, detail
(18) *Brownsfield Quadrangle*, Stuart Weller, 1916, 1917, 1918, 1924, detail

(19) *Golconda Quadrangle* (Illinois portion), Stuart Weller, 1917, detail
(Kentucky portion), Stuart Weller, 1920, detail*
(20) *Paducah Quadrangle*, Stuart Weller, 1926, detail*
(21) *Smithland Quadrangle* (Illinois portion), Stuart Weller, 1926, detail*
(Kentucky portion), Stuart Weller, 1927; A. H. Sutton, 1927, 1928, 1929, detail*
(22) *Shawneetown Quadrangle* (Illinois portion), W. T. Lee, 1915; Charles Butts, 1917, 1918, detail
(23) *Cave in Rock Quadrangle* (Illinois portion), Stuart Weller, 1917, detail
(Kentucky portion), Stuart Weller, 1922, 1923, 1926, detail*
(24) *Providence Quadrangle* (Caldwell County portion), A. H. Sutton, 1928, semi-detail*
(25) *Eddyville Quadrangle*, A. H. Sutton, 1928, 1929, detail*
(26) *Princeton Quadrangle*, Stuart Weller, 1921, detail*
(27) *Dawson Springs Quadrangle*, A. H. Sutton, 1926, detail*
(28) *Nortonville Quadrangle*, A. H. Sutton, 1927, 1929, detail*
(29) *Drakesboro Quadrangle* (Muhlenburg County portion), J. G. Woodruff, 1929, semi-detail
(Todd and Logan County portions), A. H. Sutton, 1930, detail
(30) *Dunmor Quadrangle* (Muhlenburg County portion), J. G. Woodruff, 1929, semi-detail
(Butler County portion), A. C. McFarlan, 1928, detail
(Logan County portion), A. H. Sutton, 1931, detail
(31) *Little Muddy Quadrangle* (Butler County portion), A. C. McFarlan, 1928, detail
(Warren County portion), R. F. Flint, 1925, reconnaissance
(Logan and Warren County portions), A. H. Sutton, 1931, detail
(32) *Brownsville Quadrangle* (Warren County portion), J. M. Weller, 1924, J. A. Culbertson and J. R. Griffin, 1929, detail*
(Edmonson County portion), J. M. Weller, 1924, detail
(33) *Bowling Green Quadrangle* (Warren County portion), R. F. Flint, 1925, reconnaissance
(Allen County portion), A. H. Sutton, 1930, detail*
(34) *Adolphus Quadrangle* (Allen County, Kentucky portion), A. H. Sutton, 1930, detail*
(35) *Mammoth Cave Quadrangle* (Edmonson County portion), J. M. Weller, 1924, detail
(Warren and Barren counties portion), Charles Butts, 1919, and R. F. Flint, 1925, reconnaissance
(36) *Scottsville Quadrangle* (Warren and Barren counties portion), Charles Butts, 1919, and R. F. Flint, 1925, reconnaissance
(Allen County portion), A. H. Sutton, 1930, detail*
(37) *Lafayette Quadrangle* (Kentucky portion), A. H. Sutton, 1930, detail*
(38) *Red Boiling Springs Quadrangle* (Allen County, Kentucky portion), A. H. Sutton 1930, detail*
(39) *Cannelton Quadrangle* (Ohio County portion), S. M. Mayfield, 1930, detail*
(Breckenridge County portion), J. A. Culbertson and J. R. Griffin, 1930, semi-detail*
(40) *Hardinsburg Quadrangle*, J. R. Griffin, 1929, semi-detail*
(41) *Falls of Rough Quadrangle*, S. M. Mayfield, 1930, detail*
(42) *Kirk Quadrangle* (not mapped topographically) (Breckenridge County portion), J. A. Culbertson and J. R. Griffin, 1930, semi-detail*
(Grayson County portion), J. M. Weller and A. H. Sutton, 1925, reconnaissance
(43) *Spring Lick Quadrangle*, J. A. Culbertson and J. R. Griffin, 1929, reconnaissance
(44) *Leitchfield Quadrangle* (Grayson County portion), J. A. Culbertson and J. R. Griffin, 1929, reconnaissance*
(Edmonson County portion), J. M. Weller, 1924, detail
(45) ——— *Quadrangle* (not mapped topographically) (Meade County portion), A. H. Sutton and O. E. Wagner, 1930, reconnaissance
(Breckenridge County portion), J. A. Culbertson and J. R. Griffin, 1930, semi-detail*
(Hardin County portion), J. M. Weller and A. H. Sutton, 1925, reconnaissance
(46) *Big Clifty Quadrangle*, J. A. Culbertson, 1929, semi-detail*
(47) *Cub Run Quadrangle* (Edmonson County portion), J. M. Weller, 1924, detail
(remainder of quadrangle), A. H. Sutton, 1927, reconnaissance

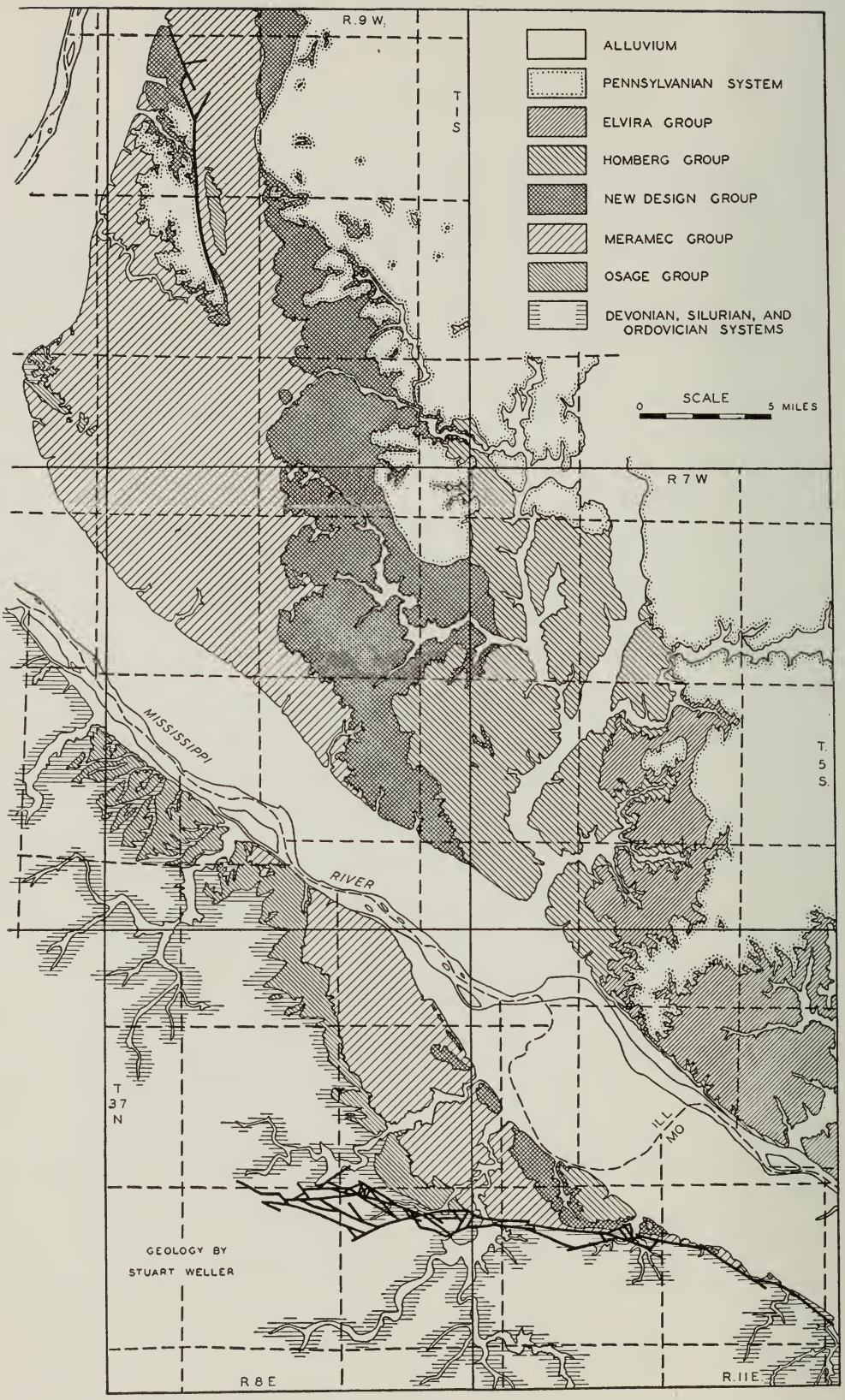

FIG. 4.—Areal geologic map of parts or all of following quadrangles: Kimmswick, Waterloo, New Athens, Crystal City, Renault, Baldwin, Weingarten, Chester. See index map (Fig. 3). Geologic mapping under auspices of Illinois State Geological Survey and Missouri Geological Survey.

Chester may be assumed to have accumulated much more rapidly. It seems logical, therefore, to consider that the Chester, in spite of its much greater thickness, represents an interval of time more nearly comparable to that of each of the two proposed lower divisions.

3. What appear to be the two most important unconformities in the Mississippian system in its type area occur (a) between the Kinderhook and Osage groups and (b) between the Meramec group and Chester series.

4. With this arrangement the most typical and earliest studied Mississippian faunas fall within the middle division. The Kinderhook or lowermost division contains faunas whose molluscan elements are strongly suggestive of the Devonian, and the uppermost division, the Chester series, contains faunas whose molluscan portion characteristically has strong Pennsylvanian affinities.

BASAL STRATIGRAPHIC RELATIONS

The relations of the Mississippian and Devonian systems in the central United States are confused because throughout large areas a thick shale formation, commonly black and generally barren of diagnostic fossils, lies between strata containing respectively Devonian and Mississippian faunas. The age of this shale has been the subject of much discussion. Fossils recently collected from the lower and upper parts of the formation in central Kentucky show that both upper Devonian and lower Mississippian strata are present (51, pp. 17, 50). However, the shale in other areas may be either entirely Devonian or entirely Mississippian, and so every area must be considered separately. Although the remarkably uniform character of the shale indicates that conditions of sedimentation must have been similar during late Devonian and early Mississippian time, unconformities reported at some places may indicate at least local breaks in sedimentation whereas at other places, where unconformities have not been recognized, sedimentation may have been continuous.

Whatever its age, this black shale directly underlies undoubted Mississippian strata throughout the Eastern Interior basin except along the border of the Ozark region in western Monroe and southern Calhoun counties, Illinois, and adjacent parts of Missouri, where its absence may be either the result of non-deposition or of pre-Osage erosion. Wherever it crops out around the borders of the basin it lies unconformably on lower beds. The unconformity is particularly marked high on the Cincinnati arch and on the northeast flank of the Ozarks where the shale rests on formations ranging in age from Middle Devonian to Middle Ordovician. The presence of such a pro-

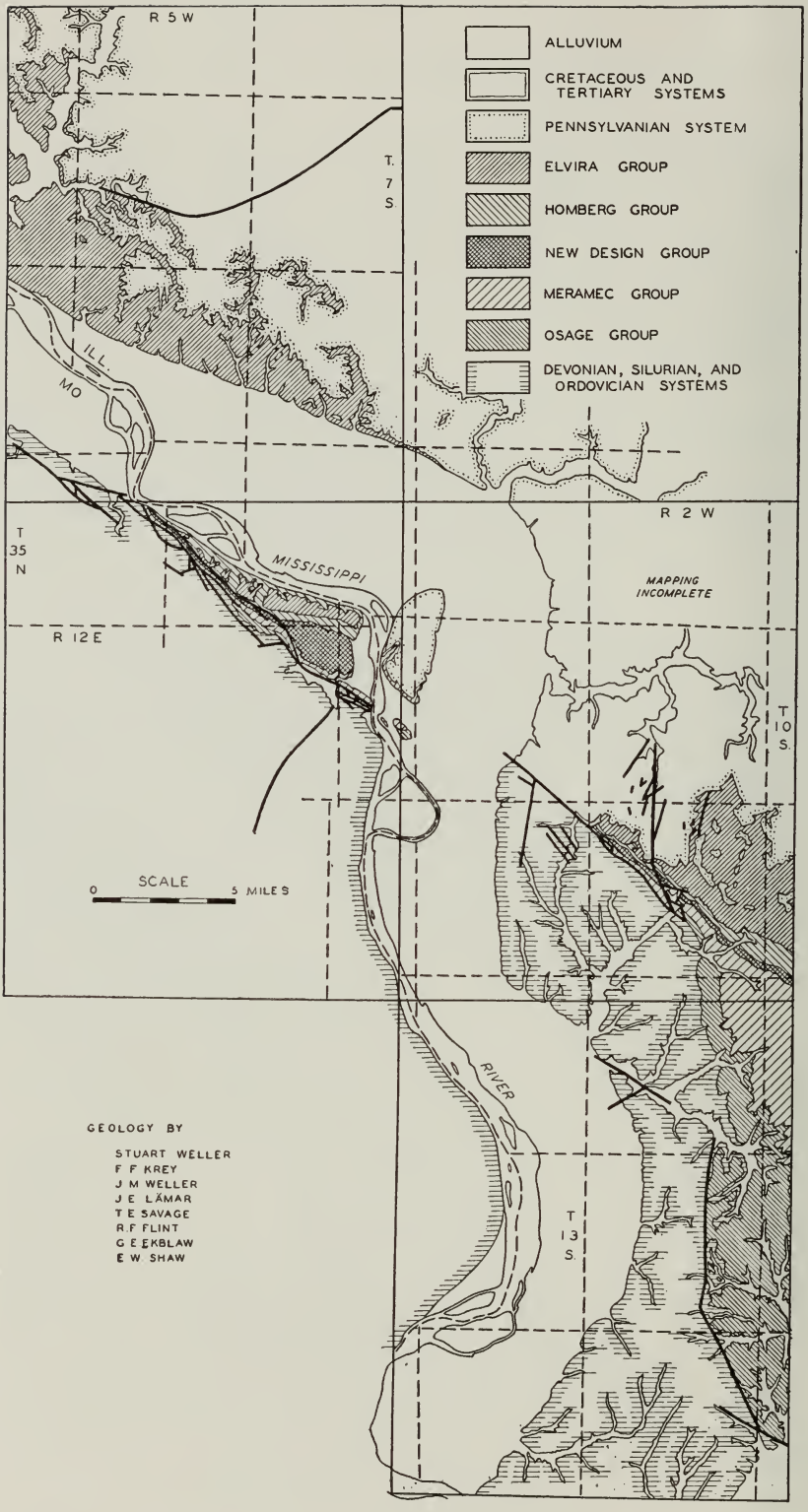

FIG. 5A.—Areal geologic map of parts or all of following quadrangles: Campbell Hill, Murphysboro, Altenburg, Alto Pass, Jonesboro. See index map (Fig. 3). Geologic mapping under auspices of Illinois State Geological Survey and Missouri Geological Survey.

nounced unconformity beneath the black shale in the Mississippi valley has been cited as evidence that the shale is early Mississippian in age, in spite of the fact that its lower portion in Kentucky and Indiana, where an equally great unconformity occurs, is certainly Devonian.

Branson and Mehl have recently pointed out that the conodonts of the lower Kinderhook belong to Devonian genera and mainly on this basis they propose to exclude from the Mississippian system all strata below the base of the Hannibal shale (3, pp. 179–83; 4, p. 5). This conclusion does not appear to be entirely justified, as other faunal evidence is not in harmony.

IOWA SERIES

The Iowa series consists of those beds which for many years have been termed lower Mississippian in distinction from the Chester or upper Mississippian series. It includes the Kinderhook, Osage, and

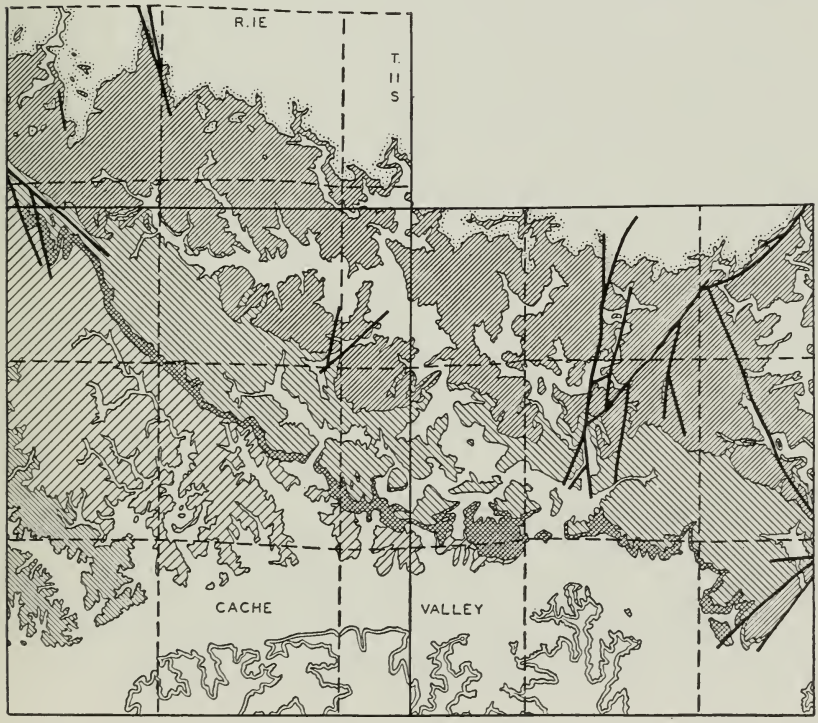

FIG. 5B.—Areal geologic map of parts or all of following quadrangles: Carbondale, Dongola, Vienna. See index map (Fig. 3). Geologic mapping under auspices of Illinois State Geological Survey.

Meramec groups and was named from the state of Iowa in which two of its most important formations, the Burlington and Keokuk limestones, have their typical development. In the Mississippi Valley area the Iowa series is composed principally of massive cherty limestone but eastward it grades irregularly into clastic sediments and in Indiana only the upper part continues as persistent limestone.

KINDERHOOK GROUP

The basal group of the Mississippian system receives its name from Kinderhook, Pike County, Illinois, where good exposures occur in the east bluffs of the Mississippi River valley. Its lithology, stratigraphy, and faunas are so diverse that no single stratigraphic section can be considered typical. It consists of several formations, most of them more or less local in distribution, the correlation of some of which is still tentative.

New Albany shale.—The New Albany shale, of which at least the upper portion at some places is of Kinderhook age, receives its name from New Albany, Floyd County, Indiana. It consists largely of hard, black, sheety shale and is therefore an easily recognized horizon in subsurface work. It crops out in a continuous band extending southeastward through central Indiana from Jasper County to Ohio River and thence encircles the Blue Grass region of Kentucky. At its outcrops in Indiana it varies little in thickness, averaging about 100 feet, but in Kentucky it thins southward so that near the Tennessee state line it averages only 25–35 feet thick. It thickens, however, toward the deepest part of the basin, as drillings in Kentucky record 150 feet near Bowling Green, 160 feet near Owensboro, 242 feet near Princeton, and 255 feet near Kuttawa, and on Hicks dome in Hardin County, Illinois, where it has been called Chattanooga shale, it has a reported thickness of 400 feet (87, p. 87)

Mountain Glen shale.—A hard, black, sheety shale, which crops out in southwestern Illinois and which has been named Mountain Glen shale after a town in Union County, is correlated with the upper part of the New Albany shale (50, p. 177). It lies unconformably on Devonian limestone and attains a maximum thickness of nearly 50 feet.

Grassy-Saverton shale.—The name Grassy Creek was originally proposed by Keyes (28, p. 63) for "black and green shales" lying beneath the Louisiana limestone at Louisiana and elsewhere in Pike County, Missouri. Later, Keyes restricted this name in abbreviated form to the lower, black beds and proposed the name Saverton for the upper greenish or bluish beds (29, p. 160). Subsequently Krey

(30, p. 23) determined that, although black shale of Mississippian age does occur in the drainage basin of Grassy Creek, the dark shales conspicuously exposed along that stream (correlated by Keyes and Rowley (28, p. 63; 45, p. 24) with the black shale at Louisiana) are not equivalent to the beds exposed at Louisiana, as they respectively underlie and overlie the Silurian Noix oölite which is locally absent along Grassy Creek. Re-study of these localities has demonstrated that the black shale on Grassy Creek is a member of the Maquoketa and if this place be accepted as the type locality the name Grassy Creek or Grassy may not be used for the black shale at the base of the local Mississippian section. It has been proposed by Weller (73), therefore, that the name Saverton be expanded to include the black shale lying conformably beneath the typical Saverton.

Because the basal black shale of the Kinderhook and that of the overlying greenish or bluish beds appear to be perfectly conformable, and because the black shale is believed to grade laterally into lighter-colored and less laminated shale, it is doubtful if these two members deserve recognition as separate formations. Branson and Mehl (3, pp. 171–74), as well as others, have continued to refer to this entire interval as Grassy Creek shale. Because of uncertainty regarding the status of the names Grassy Creek and Grassy, the term Grassy-Saverton shale is tentatively employed in this paper.

The Grassy-Saverton shale consists in ascending order of thin basal sandstone, black, hard, sheety shale, and thicker, bluish or greenish argillaceous shale. The basal sandstone, a few inches thick, is present at Louisiana and other places in Pike County, Missouri. It is generally well cemented, weathers to a brownish color, and is distinguished by abundant fish teeth, bone fragments, coprolites. and black phosphatic nodules.

The black shale member is thinly laminated, hard, brittle, and very carbonaceous. It is 20 feet thick in parts of Pike and Calhoun counties, Illinois, but at Louisiana, Missouri, it is only 4 feet thick, and farther south it thins and disappears. It is reported in wells for some distance east, north, and possibly west, beyond its area of outcrop. Farther northeast, however, it loses its black color and becomes dark gray silty shale.

The main and uppermost or Saverton member of the formation consists of bluish or greenish argillaceous shale which is 80 feet thick at its type locality near Saverton although it is said to increase to 100 feet elsewhere in Ralls County. This shale thins southward, being only $1\frac{1}{2}$–2 feet thick at Louisiana, but extends beyond the limit of the underlying black shale member before it pinches out entirely. It is

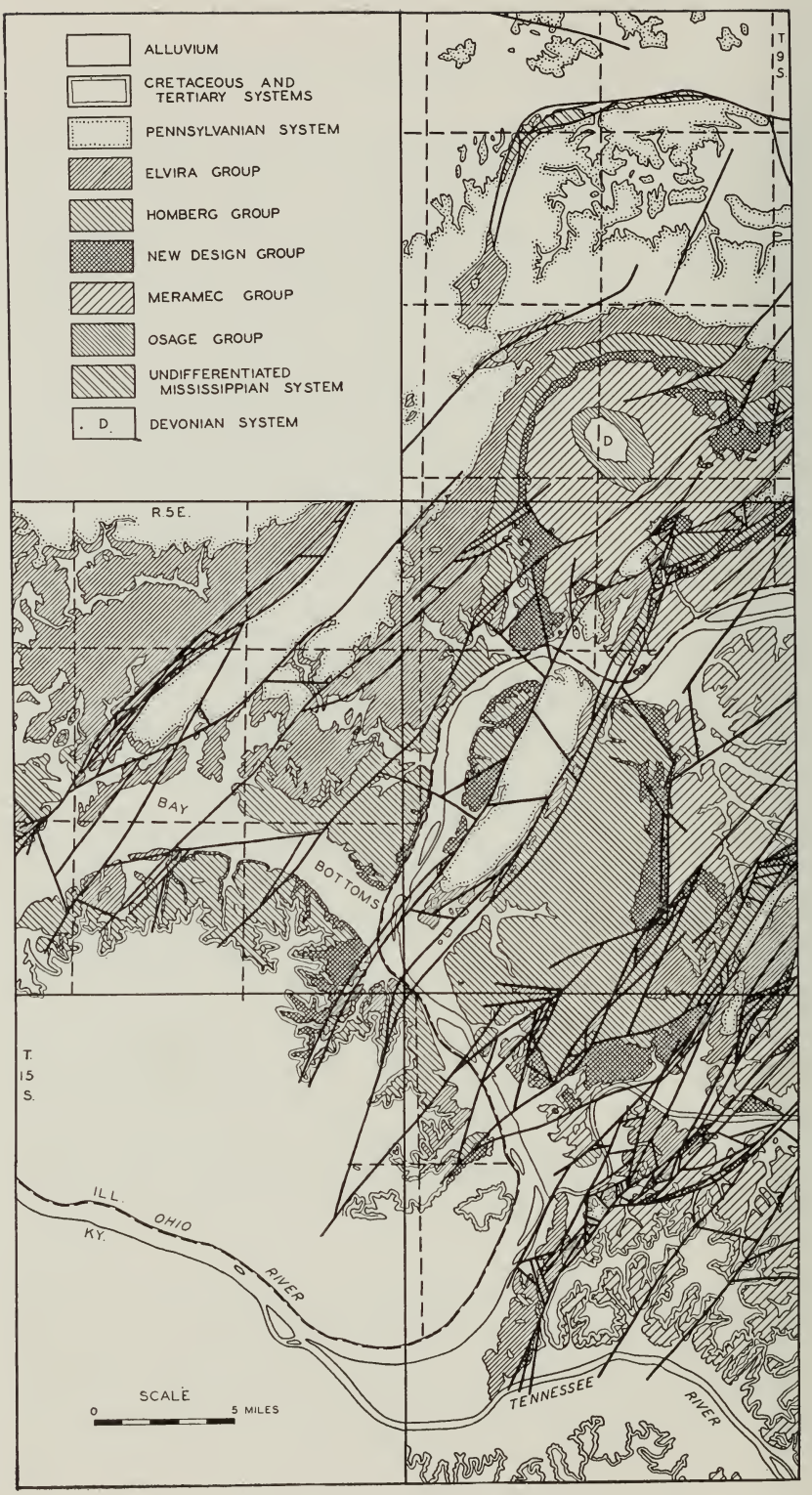

FIG. 6A.—Areal geologic map of parts or all of following quadrangles: Equality, Brownsfield, Golconda, Paducah, Smithland. See index map (Fig. 3). Geologic mapping under auspices of Illinois State Geological Survey and Kentucky Geological Survey.

FIG. 6B.—Areal geologic map of parts or all of following quadrangles: Shawneetown, Cave in Rock, Providence, Eddyville, Princeton. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey and Illinois State Geological Survey.

below drainage on the north at Hannibal but crops out in central Marion County, Missouri, and its presence in a considerable area beyond is revealed by drill records.

The Grassy-Saverton shale is apparently equivalent to part of the lower Kinderhook section of southeastern Iowa, where it has been designated "Kinderhook Bed 1" at Burlington (76, p. 60) and Maple Mill shale in Washington County (1, p. 127), and probably also to the Sweetland Creek beds of Muscatine County.

The Grassy-Saverton shale lies unconformably on beds ranging in age from Ordovician to Devonian and appears to pass conformably into the Louisiana limestone above. It is possible that the great thickness of this limestone at Louisiana, where the Saverton is thin, and the much thinner Louisiana limestone farther north, where the Saverton is thicker, is evidence that the Louisiana limestone began to be deposited on the south while Saverton shale was still accumulating on the north.

Sweetland Creek beds.—A series of about 50 feet of interbedded black and greenish shale and argillaceous magnesian limestone which is exposed along the Mississippi valley in southern Muscatine County, Iowa, has been named Sweetland Creek after the stream along which the beds are best exposed (62, p. 289). These beds rest unconformably on the Cedar Valley limestone (Devonian) and are overlain also unconformably by Pennsylvanian sandstone. The basal layer contains

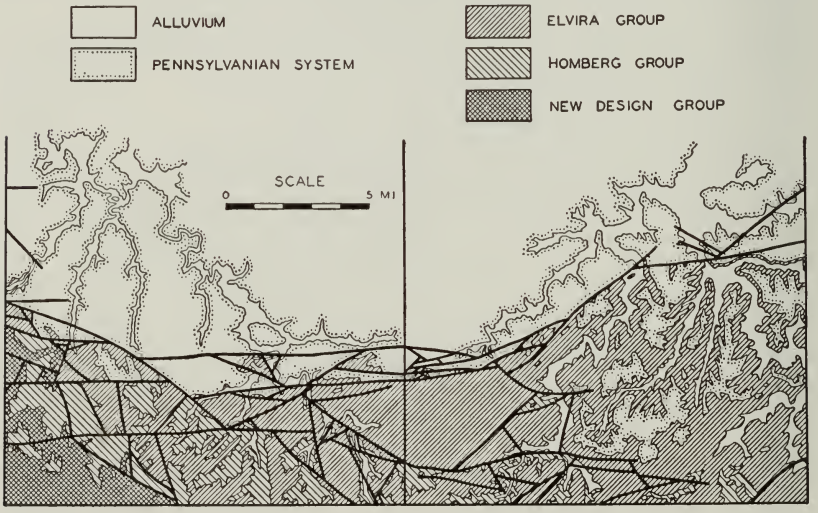

FIG. 7A.—Areal geologic map of parts of Dawson Springs and Nortonville quadrangles. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey.

abundant fish teeth, but as no diagnostic fossils are known the age of these beds is somewhat uncertain. They have been considered Devonian by some (62, pp. 301–03; 13, pp. 192–97), but the more recent tendency is to include them in the Kinderhook series (82, p. 274; 67, p. 71; 41, p. 36; 33, p. 352).

In recent reports of the Illinois State Geological Survey the name Sweetland Creek shale has been used for a series of dark-colored shales commonly reaching a thickness of 100–200 feet and encountered in deep wells between the Devonian and Mississippian limestones. The shales contain numerous spores similar to, or indentical with, *Sporangites huronense* which are common in the black shales of the New Albany, Mountain Glen, Grassy-Saverton, and Sweetland Creek formations and also occur in certain parts of the lighter-colored shales of the Saverton and Sweetland Creek formations, in another black shale overlying the Glen Park limestone of Missouri, and in the Hannibal shale. It follows therefore that the "Sweetland Creek" shale of Illinois subsurface studies may include representatives of any or all of the afore-named formations.

Almost every well that has penetrated to sufficient depth in the entire Eastern Interior basin has encountered dark *Sporangites*-bearing shale between the Devonian and Mississippian limestones and it is clear that the New Albany shale of Indiana and central Kentucky, the "Chattanooga" shale of southeastern Illinois, the Mountain Glen shale of southwestern Illinois, the Grassy-Saverton shale of northeastern Missouri, and the Sweetland Creek shale of

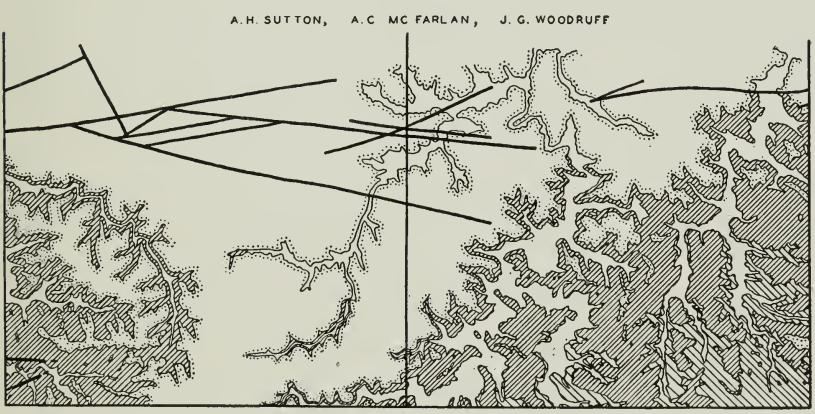

FIG. 7B.—Areal geologic map of parts of Drakesboro and Dunmor quadrangles. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey.

southeastern Iowa are the outcropping edges of a continuous, extensive, and easily recognized series of dark shales all more or less equivalent although not necessarily of exactly the same age.

Louisiana limestone.—A conspicuous lithographic limestone member of the Kinderhook series in northeastern Missouri is named Louisiana after the town of Louisiana in Pike County. This limestone is dense, fine-grained, and light gray where fresh but weathers to light yellowish brown. It occurs in evenly bedded layers with distinct partings and breaks with a conchoidal fracture. The Louisiana crops out at many places in Marion, Ralls, and Pike counties, Missouri, reaching a maximum thickness of nearly 70 feet near Ilasco in Ralls County. It rarely exceeds a thickness of 5 feet in Illinois and pinches out completely in southern Calhoun County. To the north it thins as the Saverton shale thickens, suggesting that the upper part of the Saverton shale in the north may have accumulated contemporaneously with the lower part of the Louisiana where it is best developed.

The McCraney[7] lithographic limestone in Pike County, Illinois, (41, pp. 20–23, 49–60) and the lithographic bed at Burlington, Iowa, are lithologically similar to the Louisiana limestone and future studies may prove them to be equivalent.

Sulphur Springs formation.—The Sulphur Springs formation in southeastern Missouri consists of an unnamed basal shale member, the Glen Park oölitic limestone in the middle, and the Bushberg sandstone at the top, all three names being derived from towns in Jefferson County. The basal shale is argillaceous and yellowish brown. It is known to crop out only in its type area, where it attains a thickness of 15 feet. This may represent the Saverton shale of northeastern Missouri. The Glen Park limestone, which ranges in thickness from 1 to 15 feet, is light gray, more or less impure oölitic limestone at its type locality but farther south in Ste. Genevieve County it is gray to yellowish arenaceous limestone with lenticular oölitic beds and contains phosphatic nodules. The Bushberg sandstone, which has a maximum thickness of about 10 feet, is soft, coarse, and yellowish brown. Locally its basal portion is a conglomerate containing phosphatic pebbles and fish teeth. It is probably equivalent to the lower part of the Hannibal shale.

The Sulphur Springs formation lies unconformably on Ordovician strata. In Ste. Genevieve County it is overlain by hard, black, evenly laminated *Sporangites*-bearing shale which is also probably equivalent to part of the lower Hannibal shale.

[7] This member takes its name from a creek that reaches the Mississippi bottoms a short distance above Kinderhook. In the original paper (41) the name was incorrectly spelled McKerney.

Hannibal formation.—The name Hannibal, after a town in Marion County, Missouri, has been given to a series of siliceous shales with more or less sandstone, which reaches a maximum thickness of about 100 feet in Pike County, Missouri, and northern Calhoun County, Illinois, and thins south and southwest. The formation is characteristically bluish or brownish green and weathers to a brownish color. In its southern exposures it is mainly a non-laminated earthy shale but northward it becomes increasingly siliceous and coarser-grained and consists more or less of very fine sandstone or siltstone in which worm borings are locally abundant. Because of these borings it has been termed the Vermicular sandstone.

At the base of the Hannibal formation in Jersey and Calhoun counties, Illinois, and St. Charles County, Missouri, occurs a maximum thickness of 25 feet of sandy limestone, some beds of which are more or less oölitic, interstratified with shales. These beds have been named the Hamburg oölite after the town of Hamburg, Calhoun County, Illinois, where they immediately overlie the Louisiana limestone. The fauna of the Hamburg oölite is similar to that of the Glen Park limestone in the Sulphur Springs formation of southeastern Missouri. In Calhoun County, Illinois, dark laminated shale occurs in the middle part of the Hannibal formation.

The Hannibal formation as recognized near Kinderhook, Illinois, and at Burlington, Iowa, is divisible into four members (30, pp. 36–37; 41, pp. 20–24). The Maple Mill shale at the base consists of bluish argillaceous beds that are locally calcareous or silty. This member grades upward into the English River (or *Conopectus*) sandstone, which is massive, fine-grained, and weathers to a buff color. They are each about 20 feet thick at Burlington but achieve about double that thickness at Kinderhook. These are succeeded by the McCraney (McKerney) member consisting of gray to drab lithographic limestone up to 15 feet thick which at Burlington is underlain by a few inches of gray crystalline limestone and white oölite and is overlain by a foot or two of brownish dolomitic limestone. At the top is the Prospect Hill member, a soft drab-weathering fine-grained sandstone 6 feet thick at Burlington and 10 feet thick at Fall Creek, Illinois.

The McCraney limestone is lithologically similar to the Louisiana limestone and as these two beds have nowhere been observed in the same section it is possible that they are equivalent. If so the Maple Mill shale and English River sandstone are members of the Saverton. Both of these names, however, are derived from localities in Iowa considerably removed from the various well known Kinderhook sections and their relations to each other and to these sections have not yet been fully established.

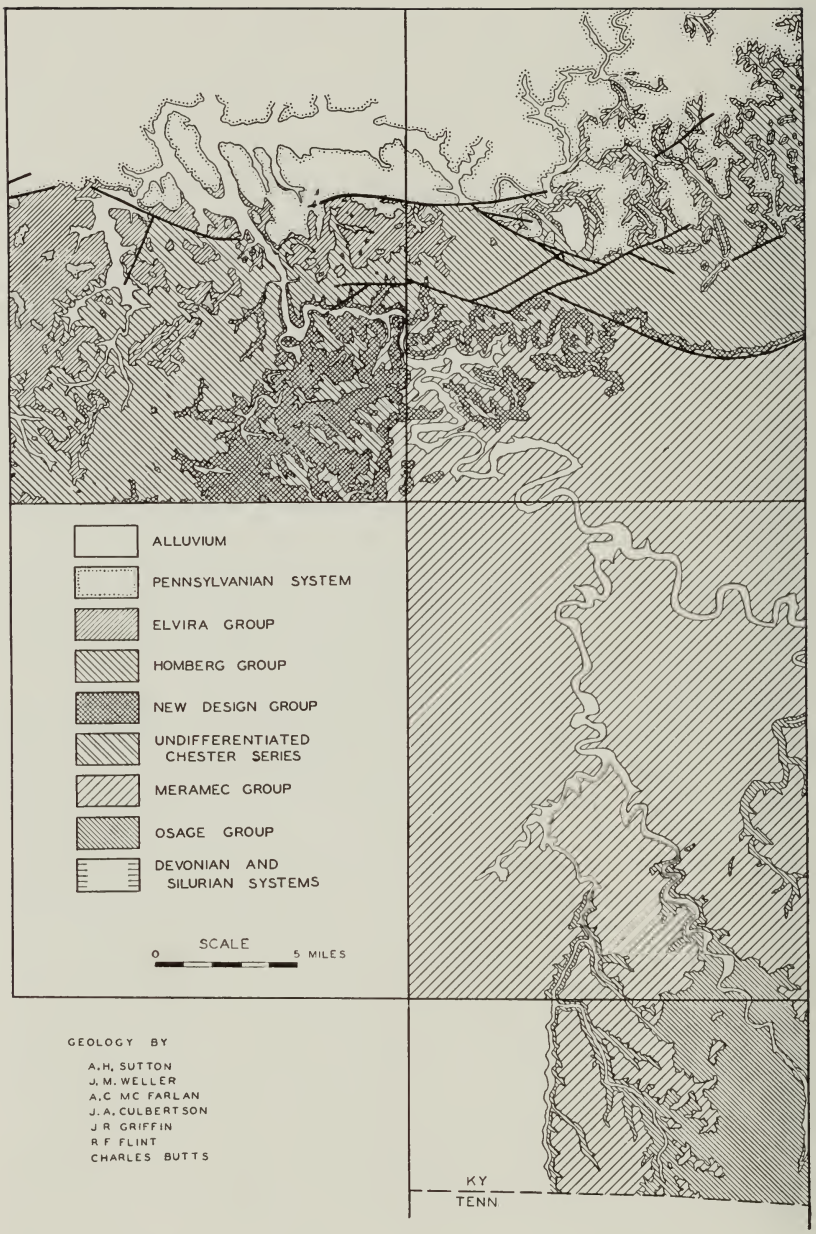

FIG. 8A.—Areal geologic map of part or all of following quadrangles: Little Muddy, Brownsville, Bowling Green, Adolphus. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey.

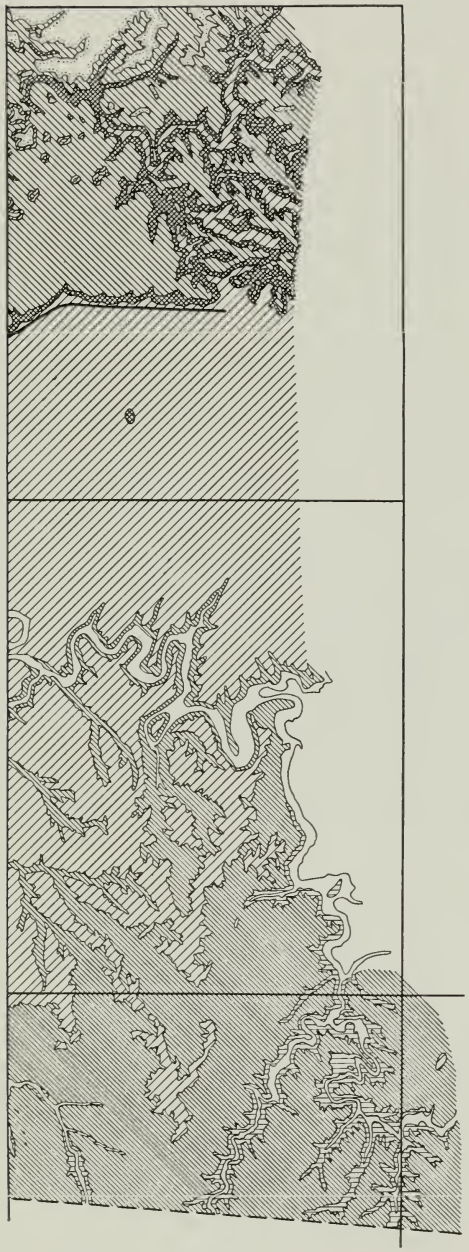

FIG. 8B.—Areal geologic map of part or all of following quadrangles: Mammoth Cave, Scottsville, LaFayette, Red Boiling Springs. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey.

Springville shale.—A shale, with a maximum thickness of about 60 feet, which crops out in southwestern Illinois, has been named Springville from a village in Union County. It is bluish to greenish gray where fresh but weathers to a variegated mottling of white, red, and brown for which reason it was termed "Calico shale" in the Worthen reports. The lower part of this formation is soft and argillaceous with occasional calcareous layers, but the upper part is hard and silicified. It overlies the black Mountain Glen shale unconformably and rests on Devonian limestone where the black shale is absent. It also is reported to be unconformable with the overlying cherty limestones of Osage or Meramec age. Fossils are rare in the Springville shale but are present in a thin limestone locally present at the base of the formation and prove its Kinderhook age. It is tentatively correlated with the Hannibal formation.

Chouteau limestone.—The uppermost formation of the Kinderhook series in the western part of the Eastern Interior basin is correlated with the Chouteau limestone of central Missouri. It is dolomitic, earthy, lithographic, or crystalline in texture, is brownish, gray, or almost white in color, and contains many small calcite geodes. It reaches its maximum thickness of about 60 feet in Calhoun County, Illinois, but is absent throughout a considerable area where over- and underlying beds are in contact. It succeeds the Hannibal formation conformably and thins where the Hannibal thickens so that their combined thickness remains nearly constant.

At Burlington, Iowa, the Chouteau is probably represented by a 3-foot oölitic limestone which occurs at the top of the Kinderhook section.

Rockford limestone.—A thin limestone of very constant lithologic character is the only representative of the Kinderhook series definitely recognized in Indiana. It is named from Rockford in Jackson County where it has yielded an interesting fauna, including numerous goniatites on account of which it was formerly known as the Goniatite limestone. The Rockford limestone commonly varies in thickness from 1 to a maximum of 3 feet and, except at its thicker exposures, consists of a single bed which produces many small waterfalls. It is dense brittle limestone of almost lithographic texture, gray mottled with greenish specks and streaks where fresh, but weathers to yellowish brown. Beneath it and separating it from the New Albany shale at many places is a 2- to 6- inch zone of bluish green clay shale with green glauconitic specks. The Rockford limestone is uniformly present from its type locality southward to Ohio River but has not been recognized in Kentucky. Although its fauna is suggestive of the

Chouteau it can not be definitely correlated with any of the Mississippi Valley formations.

KINDERHOOK SEDIMENTATION

The conditions of deposition of the remarkably uniform black shale, which may in part constitute the base of the Kinderhook group throughout nearly all of the Eastern Interior basin, have been the subject of much difference of opinion but it seems most likely that these beds are an accumulation of colloidal material carried from low-lying land into an extensive shallow sea. Coarser clastic materials form a conspicuous part of the succeeding strata in the Mississippi valley and on the flank of the Ozark region, and possibly also northwestward in Iowa they overlap the black shale onto older beds. The absence of easily recognizable Kinderhook beds, except the thin Rockford limestone, along the eastern border of the basin suggests either that the New Albany shale may include in its upper part beds representing nearly the entire Kinderhook series or that this area was largely emergent during Kinderhook time.

Sedimentary conditions in the Kinderhook sea varied greatly from place to place and from time to time but the causes for this variation are not known. Ozarkia existed as a land area for a time at least, because the Bushberg sandstone of southeastern Missouri and the Sylamore sandstone of central Missouri, with which it has been correlated, contain grains that were almost certainly derived from Ordovician beds cropping out on the southwest and south. Clastic sediments were probably derived to a greater extent, however, from other sources. The Hannibal formation thickens and becomes more sandy toward the north and these sediments may have been derived from the erosion of earlier Paleozoic formations exposed in northern Illinois and adjacent area. The clastic character of the Waverly series of Ohio, the lower portion of which is certainly Kinderhook in age, is evidence that Appalachia was a land area undergoing erosion during early Mississippian time, but the absence of similar strata along the eastern margin of the Eastern Interior basin suggests that the Cincinnati arch at this time may have existed as an effective barrier separating two sedimentary provinces.

KINDERHOOK PALEONTOLOGY

The Kinderhook group is generally non-fossiliferous, but restricted horizons at some localities contain an abundance of specimens. These faunas of restricted distribution evidently reflect local ecological factors and consequently are so varied that precise correlation of the strata is difficult. They fall into two general types, how-

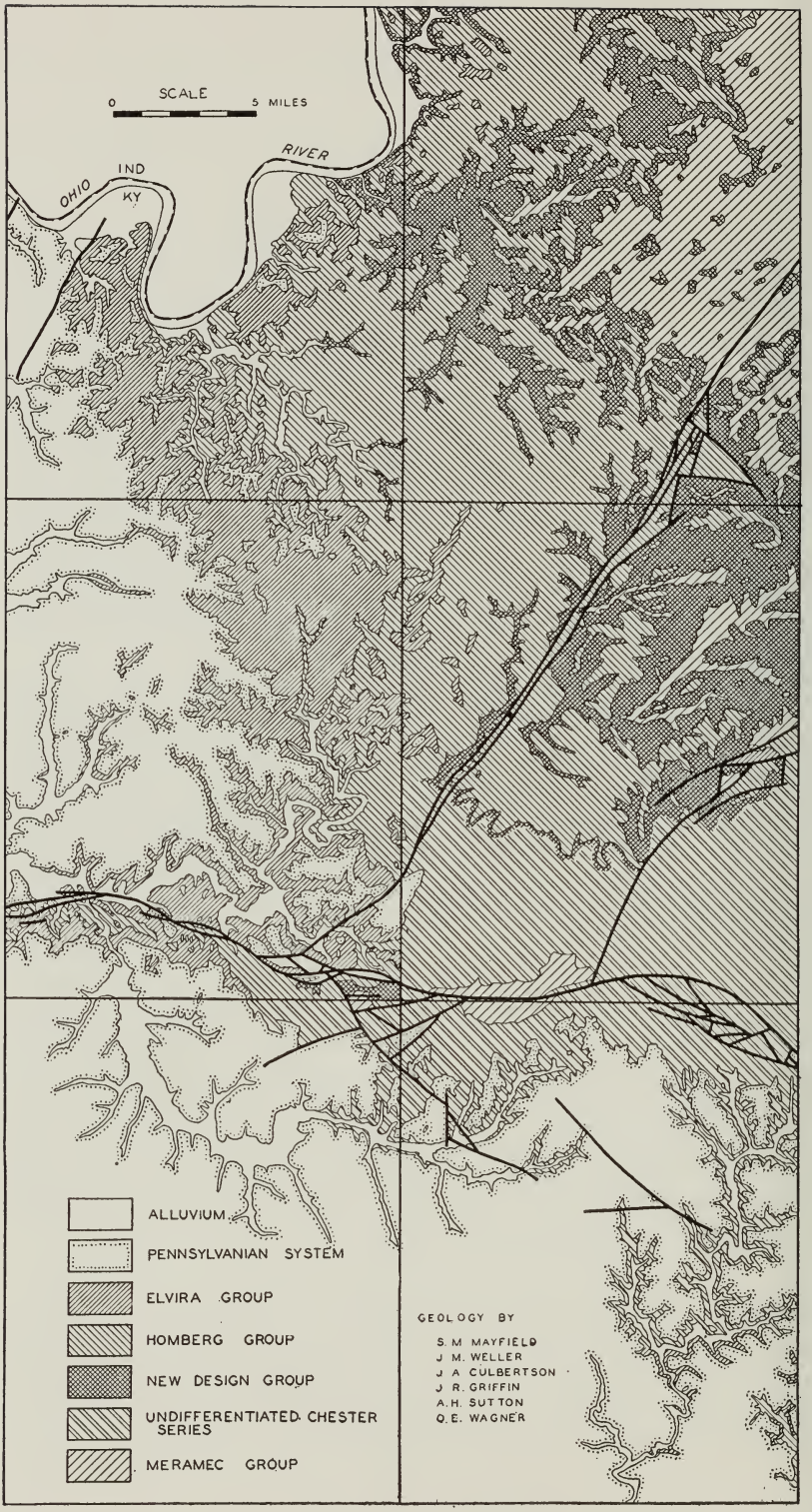

FIG. 9A.—Areal geologic map of part or all of following quadrangles: Cannelton, Hardinsburg, Falls of Rough, Kirk, Spring Lick, Leitchfield. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey.

FIG. 9B.—Areal geologic map of part or all of following quadrangles: one unnamed, Big Clifty, Cub Run. See index map (Fig. 3). Geologic mapping under auspices of Kentucky Geological Survey.

ever, one of which is represented in the English River (*Chonopectus*) sandstone and the Louisiana limestone and the other is characteristically developed in the Chouteau limestone and occurs also in the Glen Park limestone and Hannibal formation. The differences between these faunas are not obvious, but the *Chonopectus* fauna contains residual Devonian elements most closely related to the Chemung of New York while similar forms in the Chouteau fauna have Hamilton relationships. Although the *Chonopectus* fauna occurs in beds which underlie those containing the Chouteau fauna, it is not necessarily older, as regional considerations suggest that at first the *Chonopectus* and Chouteau faunas existed contemporaneously in different basins or different parts of the same basin and that after a change of conditions in mid-Kinderhook time the Chouteau fauna migrated and supplanted the *Chonopectus* fauna in the upper Mississippi Valley area.

Because the Kinderhook faunas vary so greatly, index fossils are of only local value. However, certain genera, including the brachiopods *Paraphorhynchus* and *Chonopectus* and the pelecypod *Promacrus*, which are represented by one or more species in the Kinderhook series, are unknown from other formations in the Eastern Interior basin. The Mississippian age of the Kinderhook series is attested by several species of *Productidæ* which are associated with the last representatives of *Productella*. Spirifers of Devonian and Mississippian types are intermingled. *Spirifer louisianensis* is one of the most common species of this genus and occurs in both the *Chonopectus* and Chouteau faunas, and spirifers of high form with very narrow hinge lines, such as *S. subrotundatus* and *S. maplemillensis*, are characteristic of certain horizons. The molluscs, particularly pelecypods, are unusually well represented and provide the faunas with a strong Devonian aspect.

KINDERHOOK-OSAGE RELATIONS

The broader stratigraphic relations between the Kinderhook and Osage groups are somewhat uncertain but along the western border of the Eastern Interior basin they are generally unconformable. Definite physical evidence of an unconformity has been observed in Calhoun and in Pike counties, Illinois. In Marion, Ralls, and Pike counties, Missouri, and the adjacent part of Illinois, the Chouteau limestone is locally absent and appears to have been removed by erosion before the lowest Osage beds were deposited. In western Monroe County, Illinois, the Kinderhook is entirely absent and the Fern Glen formation (lowest Osage) rests on Ordovician strata,

although black shale similar to the New Albany is recorded in wells only a short distance east and the Sulphur Springs formation is present locally in Ste. Genevieve County, Missouri, on the west. In Union County, Illinois, the Springville shale is reported to be succeeded unconformably by middle Mississippian limestone.

It seems probable, however, that along the eastern border of the basin, no appreciable erosion occurred between the Kinderhook and the Osage epochs of sedimentation, because in southwestern Indiana, western Kentucky, and Hardin County, Illinois, no unconformity has been recognized. In Jefferson County, Kentucky, transitional beds have been reported to connect the New Albany with the overlying New Providence shale.

OSAGE GROUP

The Osage group, which receives its name from Osage River in Missouri, consists of a conformable series of more or less cherty limestones with subordinate amounts of shale. The constituent formations in the type areas have been separated mainly on the basis of lithology, and their faunas, which form a single slow evolutionary series not dependent on profound physical changes or extensive immigration of new forms, have been determined accordingly. The lithology of the various formations, however, changes laterally to such an extent that the formation boundaries can not be extended uniformly far from the type localities, and in areas of thick glacial drift and discontinuous exposures it may be impossible to subdivide the Osage group satisfactorily. The name Augusta limestone has been used in southeastern Iowa and northeastern Missouri for undifferentiated beds approximately equivalent to the Osage group. In Indiana beds of Osage age constitute the Borden group.

Fern Glen formation.—The Fern Glen formation, which is named from Fern Glen station on the Missouri Pacific Railroad 20 miles west of St. Louis, is also typically developed near Kimmswick, Missouri, and Valmeyer, Illinois. It consists of 25 to 35 feet of red calcareous shale and somewhat cherty limestone which grades upward through greenish beds into light-colored cherty Burlington limestone. The lower boundary of the Fern Glen formation is generally sharply defined, and locally it succeeds older beds with marked unconformity, as follows: the Maquoketa shale (Ordovician), near Valmeyer, Illinois; the Fernvale limestone (Ordovician) at Brickeys in Ste. Genevieve County, Missouri; the St. Laurent limestone (Devonian) at several places in Perry County, Missouri; the Bushberg sandstone (Mississippian) near Kimmswick, Missouri; the black

shale above the Bushberg at one locality in Ste. Genevieve County, Missouri; and the Chouteau limestone at Chautauqua in Jersey County, Illinois.

The Fern Glen formation is easily recognized by its red color as recorded in the logs of wells drilled some distance east of its outcrop area and south as far as Chester. Toward the north the red color disappears and the formation becomes less shaly and is not recognized by these characters beyond Jersey County, Illinois.

Sedalia limestone.—The name Sedalia has been proposed (41, p. 149) for limestone beds in central Missouri which contain a Fern Glen fauna and which have been designated by previous authors as upper Chouteau.[8] In the Mississippi Valley region above Jersey County, Illinois, the beds of Fern Glen age do not possess the typical lithologic characters of that formation but resemble the typical Sedalia limestone and are accordingly referred to it.

The Sedalia limestone of the Mississippi Valley region is generally brownish gray, earthy, dolomitic, and commonly somewhat less resistant to weathering than the underlying Chouteau or overlying Burlington beds. It is uniformly present as far north as Kinderhook with a thickness of 10–40 feet but has not been recognized at Hannibal and is apparently absent to the north as far as the base of the Osage group is exposed. It is present in southeastern Iowa, however, where it consists of magnesian limestone which has a thickness of 3–5 feet at Burlington. Farther northwest the Wassonville limestone is apparently equivalent to the Sedalia. Like the Fern Glen, the Sedalia lies unconformably on the Chouteau limestone and older beds.

Burlington limestone.—The Burlington limestone is about 70 feet thick at its type locality near Burlington, Iowa, 100 feet thick in parts of northeastern Missouri, nearly 200 feet thick in Calhoun County, Illinois, and then thins to about 75 feet in Ste. Genevieve County, Missouri. In southeastern Iowa and adjacent portions of Illinois and Missouri, the Burlington formation consists of very pure, coarsely crystalline, and generally light-colored limestone with subordinate amounts of denser brownish dolomitic rock and beds or irregular masses of chert. At many places the purer limestone layers are composed almost entirely of fossil remains, especially fragments of stems, arms, and bodies of crinoids. The top of the Burlington limestone is marked throughout a wide area by a bed 2 to 10 inches thick which contains an unusual abundance of fish teeth and spines.

To the south the Burlington limestone becomes more cherty and in Ste. Genevieve County, Missouri, and Monroe County, Illinois,

[8] Branson does not recognize this subdivision of the original Chouteau and considers the Fern Glen to be a lateral facies variation of the Chouteau (4, pp. 12, 16–17).

bedded and irregular chert may constitute as much as 50 per cent of the formation, crystalline limestone beds are fewer, dense gray strata are more common, and fossils are much less abundant. In this region no distinct lithologic change occurs between the Burlington and Keokuk formations and they can be distinguished only by their fossils.

The Burlington limestone lies conformably on the Fern Glen and Sedalia formations and unconformably on older beds where the Fern Glen and Sedalia are absent.

Keokuk limestone.—The Keokuk formation, which is typically developed near Keokuk in southeastern Iowa and in adjacent parts of Illinois and Missouri, consists of 60–80 feet of interbedded limestone and chert with minor amounts of shaly material. The lower 30 feet is very cherty limestone known as the Montrose member. The limestone beds of the Keokuk vary from dense to crystalline but are generally darker and more bluish than similar strata in the Burlington.

On the south the Keokuk remains almost constant in thickness but becomes much more cherty. In Ste. Genevieve County, Missouri, it is separated into two parts by an apparent unconformity, below which the beds are lithologically indistinguishable from the Burlington and above which occurs siliceous or arenaceous limestone which passes laterally into oölite succeeded by grayish crystalline limestone with much chert. Some of the chert from the upper Keokuk weathers porous and spongy, greatly resembling ferruginous sandstone, and is very different from the dense, hard, brittle chert from lower horizons.

Burlington-Keokuk formation of southern Illinois and western Kentucky.—The increasing chert in the Burlington and Keokuk limestones on the south has been mentioned. The limestones can not be distinguished lithologically in the 100–150 feet of cherty limestone in Monroe County, Illinois, and Ste. Genevieve County, Missouri, although the fossils show that both formations are present. Farther south in Union County, Illinois, and east in Hardin County, Illinois, the Osage group consists largely of more or less evenly bedded limestone that is fine-textured, dark in color, and very siliceous. Much chert is present, and generally in Union County the lower part to a maximum thickness of about 30 feet consists of solid-bedded novaculite chert. Fossils are rare and most of them are too poorly preserved to be accurately identified, so that it is impossible to determine whether the Fern Glen, Burlington, and Keokuk are all represented in these sections. The thicknesses, however, estimated as 250–300 feet in Union County and 500–600 feet in Hardin County, suggest that the group is probably complete.

The cherty Osage beds of southern Illinois have been referred to

the Fort Payne (Tullahoma) formation of Tennessee and Alabama but as the boundaries of this formation are somewhat vague and its various parts of uncertain age, it seems preferable to designate them simply Burlington-Keokuk.

New Providence formation.—The name New Providence, which has been given to the basal formation of the Borden group, as the Osage group is termed in Indiana, is derived from the old name of the town of Borden in Clark County, Indiana. It decreases in thickness from 290 feet in Jackson and western Bartholomew counties, Indiana, to 190 feet in Jefferson and 50 feet in Pulaski counties, Kentucky. This formation is composed mainly of argillaceous poorly bedded bluish to greenish-gray shale, which readily weathers to lighter-colored clay. "Ironstone" is distributed throughout the whole formation but is more abundant in the lower part. It occurs either as continuous layers or nodules of various forms, which weather to impure limonite. Less ferruginous limestone masses or concretions which may or may not be fossiliferous and some of which are cherty are conspicuous at some localities, particularly in the vicinity of Ohio River. In Jefferson County, Kentucky, the upper 30 to 40 feet of the New Providence formation contains interbedded sandstone layers and has been termed the Kenwood sandstone from Kenwood Knob, 9 miles south of New Albany. This zone decreases in thickness both northward and southward and has not been recognized beyond east-central Floyd County, Indiana, and Lebanon Junction in Bullitt County, Kentucky. In central Brown County, Indiana, beds that appear to belong to the New Providence formation consist of heavy sandstones with thin sandy shale partings.

Southwest of the Blue Grass region of Kentucky the New Providence formation thins considerably and in Allen County, just north of the Tennessee state line, it is believed to be represented by 40 feet of grayish green shale and shaly limestone with a few rather massive layers of crinoidal cross-bedded limestone. A little chert is present and geodes are locally common.

Locust Point formation.—The Locust Point formation, which conformably overlies the New Providence, is named from Locust Point Post Office in Harrison County, Indiana. Its nearly uniform thickness is about 125 feet. From Jackson County, Indiana, southward to Ohio River it consists of slightly sandy argillaceous shale, greenish gray to bluish gray, closely resembling the New Providence shale and grades upward into shaly sandstone interbedded with grayish drab shale that weathers buff. Highly ferruginous concretions are present but are less abundant than in the underlying New Providence formation and

those in the upper part are commonly sandy. Brittle fine-grained nonferruginous limestone concretions are also present in the Locust Point formation and are more abundant in its upper part.

In northwestern Jackson County, Indiana, numerous sandstone layers abruptly appear in the Locust Point formation. They are more or less massive, evenly laminated, and weather into thin layers. Some of their surfaces show ripple marks. These sandstones are greenish gray to buff, locally chocolate-colored, and contain abundant ferruginous streaks and patches. The interbedded shales are very sandy and contain few concretions. The sandstones become thicker northward in Brown County. Eastward in Bartholomew County, where these beds have been quarried, they are relatively resistant and one sandstone 70 feet above the New Providence appears to be unusually persistent. In Monroe and western Brown County the interbedded shales become much less sandy, contain ferruginous concretions, and closely resemble the New Providence shale.

The Locust Point formation is nearly destitute of fossils except worm markings, which are abundant at many places, particularly in the upper part. It is approximately equivalent to the Rosewood shale of Jefferson County, Kentucky, which was named from the town of Rosewood in Harrison County, Indiana. Neither the Locust Point nor Rosewood formation has been distinguished in the Osage section south of Jefferson County, Kentucky.

Carwood formation.—The Carwood formation, named from the village of Carwood in Clark County, Indiana, is the most variable of the Borden formations. It overlies the Locust Point formation conformably and can not be sharply differentiated from it. Its thickness is almost uniformly about 120 feet. In the area of its typical development, which extends from northeastern Floyd to northeastern Washington County, the Carwood formation consists of light gray to bluish gray, locally iron-stained, massive but soft, arenaceous siltstone or fine sandstone that lacks conspicuous bedding and weathers drab to buff or brown. At the top of the formation occurs the Finley Knob member composed of gray to drab, locally sandy shale with a maximum thickness of 15 feet.

Northward the Carwood formation becomes more shaly, and in northern and northeastern Washington County it consists of irregular alternating shaly and sandy zones. From northwestern Washington to Brown and Monroe counties it is a nearly uniform succession of siltstones and sandy shales. In southwestern Brown and southeastern Monroe counties it is separated into two parts by the Lampkins sandstone member, which is a fine-grained gray to buff resistant

bed 1–4 feet thick occurring slightly below the middle of the formation. In this area the lower Carwood is bluish gray shale which weathers readily to clay, contains a few thin beds of sandstone, and resembles the New Providence shale. The upper part is a succession of very thinly and evenly laminated sandstone beds separated by shales. In northern Monroe, south-central Morgan, and northwestern Brown counties the Carwood is almost entirely shale, which is more sandy in the upper part but practically devoid of sandstone beds. To the east, throughout most of Brown County, this formation is exceedingly variable and more arenaceous. Plastic argillaceous shales are lacking and locally at the top there are beds of light gray sandstone of coarser texture than common.

In Floyd and Harrison counties, Indiana, and Jefferson County, Kentucky, south of its area of typical development, the Carwood formation is less arenaceous and contains a greater proportion of shaly beds in its lower part. Along Ohio River in southern Harrison County, Indiana, the massive sandy lithology of the Carwood disappears and the upper part becomes slightly but increasingly calcareous toward the south.

South of Monroe and Brown counties, Indiana, calcareous zones consisting of dense, brittle limestone layers and crinoidal lenses are present in the Carwood formation. Gray calcareous brown-weathering concretions similar to some of those in the Locust Point formation, many of which are fossiliferous, are locally particularly abundant in the middle and upper parts of the Carwood and a few small geodes are present at some places. Other concretions that are ferruginous and sandy are most common in the lower part.

Fossils, which are almost entirely absent from the Locust Point formation except for worm markings, are locally common in the Carwood formation. In general the faunules in the arenaceous beds of the formation are dominated by large brachiopods, and bryozoans are the most common fossils in the shaly strata. Worm markings are also locally abundant.

The Carwood formation is equivalent to the Holtsclaw sandstone and the upper part of the Rosewood shale of Jefferson County, Kentucky. None of these formations, however, has been differentiated in the Osage section farther south in Kentucky.

Edwardsville formation.—The Edwardsville formation, which forms the top of the Borden group, has been recognized from Warren County, Indiana, to Ohio River and in adjacent parts of Kentucky. It is named from the town of Edwardsville in Floyd County, Indiana, and increases from a minimum thickness of 45 feet near Ohio River northward to a maximum of 210 feet.

At the base of the Edwardsville is the persistent Floyds Knob member[9] which in its type area extending from northeastern Lawrence County to Ohio River, except for parts of western Clark County, consists of limestone varying in thickness, generally 3–5 feet. This member varies from almost pure limestone to very siliceous, dolomitic, ferruginous limestone that weathers to a deep yellow or chocolate color. At some places the entire rock is intermediate between these extremes and at others they are represented in different beds or different parts of the same bed. The purer limestone is crinoidal, crystalline, or oölitic and ranges from light to dark gray in color. The impure limestone leaches to a soft, porous, poorly cemented, sandy bed which crumbles to ocherous sand or silt. In parts of western Clark and adjoining counties the Floyds Knob member is represented by a single hard brittle sandstone bed or several thin sandstone layers. This member is apparently absent from the section in part of northwestern Washington County.

From northeastern Lawrence to Warren County, the Floyds Knob member consists of irregular silty calcareous brittle shaly or arenaceous strata which commonly include small nodules of chert. It weathers to a light buff, yellowish, or chocolate color or may be mottled. Where the Floyds Knob member is succeeded by calcareous beds it may not be distinguishable from them or may be represented by a thin bed of limestone that is commonly brownish and crinoidal. Its thickness in this region is generally from 4 to 5 feet.

At scattered localities throughout its extent the basal part of the Floyds Knob member is conglomeratic and contains rounded pebbles of various types apparently derived from the older Borden formations.

The typical area of the Edwardsville formation extends from southern Floyd to northern Washington County. In this region the formation above the Floyds Knob member consists of a variable succession of fairly resistant sandstones alternating with softer, more shaly beds and ranges from 40 to 75 feet in thickness. The sandstones are fine-grained and lack the perfect bedding that characterizes the Locust Point and Carwood formations. They are more abundant in the upper part of the Edwardsville than in the lower, are light gray to buff or mottled, and are somewhat ferruginous. The lower part of the formation is mainly massive soft siltstone. The shaly beds that separate the sandstones vary from bluish and argillaceous to gray-

[9] The Floyds Knob was described as a formation of the Borden group occurring between the Carwood and Edwardsville formations (54, p. 76) but its thickness is distinctly out of line with the thicknesses of the other recognized Borden formations. It possesses no known faunal pecularities and its lithology is no more distinctive than certain other Borden beds. Its only claim to recognition as a distinct formation is its unusual persistence, and the writers do not believe that this is of sufficient importance to warrent its being given more than member rank.

drab-buff and are very sandy. Upon weathering the Edwardsville formations become light buff to yellowish mottled with light gray patches.

The Edwardsville formation thickens in northwestern Washington County. The upper part is more sandy than the lower, which, above the Floyds Knob member, is fairly uniform massive soft siltstone. In northern and eastern Washington County the formation attains a thickness of 75–160 feet. Just above the Floyds Knob member a fairly persistent thick bed or several thinner beds of sandstone with a brachiopod fauna and a maximum thickness of 15 feet has been named the Brownstone Hills member. Above this the lower half of the Edwardsville is mainly sandy shale which grades into the fairly massive siltstone of the upper part of the formation. Resistant sandstone beds are present in the upper half of the formation, particularly in its lower part, and one unusually prominent and persistent bed 3–5 feet thick, that occurs 60–65 feet below the top of the Edwardsville has been named the Dry Creek member.

The thickness of the Edwardsville formation continues to increase into Monroe and Brown counties. In Monroe and southern Morgan counties it reaches a thickness of 175–210 feet. Here the beds above the Floyds Knob member may be subdivided into three parts, the lowest of which is a complex succession of evenly bedded sandstones separated by shale. A well defined resistant sandstone generally $1\frac{1}{2}$–3 feet thick and occurring 5–10 feet above the Floyds Knob is known as the Cutright member. At various places and at different horizons in this lowest part of the Edwardsville there are bioherms (reef-like limestone deposits) which may be as much as 70 feet thick and 2 miles in diameter and are characterized by the fragmental remains of crinoids and bryozoans. Near the bioherms and elsewhere where the lowest Edwardsville is more or less calcareous, there occurs about 25 feet above the Floyds Knob member an irregular 4- to 8-foot zone of sandy material which weathers to an ocherous color, contains dark brittle calcareous patches, a few small geodes, and local chert nodules, and closely resembles the Floyds Knob member. This has been named the Weed Patch member. At a few places it is a gray to brown siliceous limestone bed and at one locality it is represented by fossiliferous sandstone. The Floyds Knob member can not be distinguished from the overlying beds at many places, particularly where bioherms extend nearly to the base of the Edwardsville or where, about the bioherm margins, the sediments consist of slightly calcareous brittle shale with chert nodules.

The middle part of the Edwardsville formation in Monroe and

southern Morgan counties is 50–110 feet thick and consists of siltstone, which is most argillaceous below and massive especially in the upper part, with a few harder sandstone layers. The uppermost part of the formation is variable in thickness and well bedded and consists of alternating resistant sandstones and soft shales. A very resistant dark yellowish brown sandstone mottled with gray, which is 1–4 feet thick and occurs 5–15 feet below the top of the formation, is known as the Mt. Ebel member. It has a brachiopod fauna.

The Edwardsville formation in most of Brown County is similar to that in Monroe County except that there are no prominent bioherms and the beds are more sandy. The Weed Patch member, described above, is more persistent here than farther west and commonly attains a thickness of 4–7 feet of calcareous sandy, ocherous material but is locally represented by fossiliferous sandstone.

In Warren and Fountain counties the Floyds Knob member is overlain by evenly stratified fine-grained blue-gray sandstone that weathers brownish and locally grades into sandy shale. These beds were formerly quarried extensively along Wabash River and have been termed Riverside sandstone from a village in Fountain County.

The Edwardsville formation becomes more calcareous and cherty from north to south in southern Floyd and southeastern Harrison counties, Indiana, and Jefferson, Hardin, and Bullitt counties, Kentucky. In the transition area, calcareous beds appear first at the top of the formation and then others come in at progressively lower horizons until the entire formation consists of yellowish siliceous brittle limestone, 55–60 feet thick, with much light gray to bluish chert which weathers buff, and more or less extensive purer crinoidal lenses. Small geodes are locally common. At some places the Floyds Knob member is represented by a bed of oölite but at others it is indistinguishable. A zone of greenish glauconitic clay less than 1 foot thick overlies the Floyds Knob member at several places in Indiana. Similar greenish clay occurs at the base of the Edwardsville formation in Jefferson County, Kentucky, where the oölitic Floyds Knob member is absent.

The cherty Edwardsville limestone in Jefferson and adjacent counties, Kentucky, has generally been referred to the Warsaw formation and the name West Point member has been proposed for it[10] (58, p. 281) but it has not been distinguished as a separate unit of the section farther south.

[10] The name West Point has priority of several weeks over Edwardsville but is abandoned in favor of the latter because of the much clearer stratigraphic relations of this formation in Indiana.

Middle Osage strata in Kentucky.—The middle Osage strata in Jefferson County, Kentucky, have been referred to the basal Warsaw limestone, the Holtsclaw sandstone, and the Rosewood shale but none of these divisions has been recognized in the section more than a few miles south of Ohio River, nor has the more acceptable Indiana succession of Edwardsville, Carwood, and Locust Point formations been traced beyond this same region. Farther south the Osage beds commonly have been separated into the New Providence shale below and the Fort Payne chert and Warsaw limestone above, but this arrangement is unsatisfactory because (1) the upper boundary of the New Providence is uncertain, (2) the middle division in Kentucky, which is exclusively Keokuk in age, is not equivalent to the true Fort Payne, which contains Burlington and Kinderhook beds as well as Keokuk, and (3) the proper dividing line between beds of Keokuk and Warsaw age is doubtful. It is probable that the Indiana formations will be recognized for some distance beyond Jefferson County in Kentucky, and until the limits of the useful application of these units are determined it seems inadvisable to propose new names for this part of the section which may be temporarily termed "middle Osage strata."[11]

The middle Osage strata along the southwestern border of the Kentucky Blue Grass region consist of dark gray unevenly laminated shale, which locally becomes greenish below, and irregular lenticular limestone layers that may be light-colored, massive, and crinoidal, or bluish gray, fine-grained, siliceous, and non-fossiliferous. Upon weathering the siliceous limestone layers are commonly transformed to brittle chert. Middle Osage strata apparently decrease in thickness south of Jefferson County. In Allen and Barren counties this part of the section consists of about 100 feet of mainly massive pure coarsely crystalline and crinoidal pinkish gray cherty limestone. The chert is most abundant in the upper beds where it occurs in numerous layers 3–4 inches thick and is light brown to milky white in color. In Allen and Barren counties geodes are less abundant in the lower part of the middle Osage strata than they are in the underlying beds that are referred to the New Providence but they are locally numerous in the upper part.

Warsaw formation.—The name Warsaw was originally given to

[11] Since this paper was submitted to the editor an important publication by Stockdale has appeared in which the lower Mississippian strata on the borders of the Lexington dome in Kentucky are described. The classification proposed therein consists of (1) New Providence shale at bases overlain successively by (2) Brodhead formation (Locust Point plus Carwood of Indiana), (3) Floyds Knob formation, (4) Muldraugh formation (Edwardsville plus lower Harrodsburg of Indiana), (5) Harrodsburg (restricted) limestone, and (6) Salem limestone (54a, pp. 75–76).

18 feet of thin-bedded bluish gray limestone with interbedded calcareous shale which crops out at Warsaw in Hancock County, Illinois, (22, p. 193) but was soon expanded to include about 50 feet of strata lying between the geode beds and the St. Louis limestone (23, p. 97). Subsequently 8 feet of cross-bedded yellowish weathering limestone grading locally into calcareous sandstone which occurs immediately below the St. Louis limestone was removed from the Warsaw at its type locality and assigned to the Salem limestone (81, p. 163), and the geode beds, which had formerly been included in the Keokuk, were transferred to the Warsaw formation (6, p. 157; 67, p. 185). As the Warsaw formation thus defined was considered exactly equivalent to the Harrodsburg limestone of Indiana (6, p. 157; 16, p. 493) the latter name was abandoned because Warsaw had priority.

The lower division of the Warsaw formation, which at its type locality is about 36 feet thick and has been termed the "geode beds," consists of massive fine-grained earthy gray geode-bearing limestone below, a thin bed of locally brownish dolomitic cherty limestone in the middle, and bluish gray tough slightly calcareous geode-bearing shale above. At Keokuk, Iowa, this basal member of the Warsaw has thinned to less than 30 feet and it apparently pinches out entirely a short distance farther north. Shaly beds are more persistent southward, however, and dominate the lower part of the Warsaw as far south as Ste. Genevieve County, Missouri, and Monroe County, Illinois. In Calhoun County, Illinois, this zone is about 50 feet thick and consists of soft somewhat calcareous gray to greenish gray shale with interbedded layers of brownish argillaceous and somewhat dolomitic limestone, particularly in the upper and lower parts. Geodes are present. In Ste. Genevieve County, Missouri, and Monroe County, Illinois, the shaly lower Warsaw is also about 50 feet thick. It consists of bluish gray to buff shale with a variable number of limestone lenses.

Apparently the upper division of the Warsaw formation has not been distinguished from the overlying Salem everywhere in western Illinois and adjacent parts of Missouri. At Warsaw it reaches a thickness of nearly 40 feet and is composed of bluish gray shale with thin interbedded layers of argillaceous limestone, a few thin beds of fine-grained bluish gray sandstone, and several massive bluish gray dense to finely crystalline limestone strata which locally are irregularly and incompletely dolomitized. It thins northward and disappears from the section a short distance north of Keokuk. South of Warsaw this part of the formation becomes increasingly calcareous and has probably been included in the Salem or Spergen formation. In Ste. Genevieve County, Missouri, and Monroe County, Illinois, the upper

Warsaw consists of about 60 feet of gray to buff fine-grained more or less earthy and locally dolomitic limestone. It is nearly free from chert although a moderate amount is present in the lower part at some places. Near the top some beds are more crystalline than the other strata.

The Warsaw and Salem limestones have not been separated in southern Illinois and western Kentucky, where they attain a combined thickness of 200 to 250 feet. In Union County, Illinois, they consist of dominantly light-colored coarse-grained limestone, part of which may be oölitic. Dense bluish gray cherty layers occur in both the lower and upper parts of the formation. In Hardin County, Illinois, the lower three-fourths of this succession is mainly nearly black dense somewhat cherty limestone and the upper fourth, which may be Salem, is composed of light gray coarse-grained thick-bedded limestone with interbedded zones of darker shaly limestone and shale.

In Allen County, Kentucky, where the Salem limestone has not been recognized, about 100 feet of strata have been assigned to the Warsaw formation, the lower 20 feet of which consist of shaly limestone with interbedded coarsely crystalline layers and the remainder of bluish gray thin-bedded cherty limestone containing many geodes. In northern Hardin County, Kentucky, the Warsaw formation, including the few feet of limestone above the Somerset shale that may be equivalent to the Salem, reaches a maximum of about 220 feet. Because the Edwardsville formation of the Borden group has commonly been included in the Warsaw formation in Jefferson, Hardin, and adjoining counties, Kentucky, its reported thicknesses there are too great by 50 feet or more. It is uncertain to what extent similar errors have been made farther south along the margin of the Blue Grass region where the Warsaw formation consists of limestone and shale in variable proportions. The limestone is mostly gray to bluish gray, coarse-grained and crinoidal, and certain beds are notably cross-bedded. The shaly beds and partings are generally bluish gray and highly calcareous. A shaly zone with interbedded limestone layers, which is present in the upper part of the formation and attains a thickness of 20 to 50 feet, is correlated with the Somerset shale member of eastern Kentucky and may be equivalent to the shale underlying the Salem limestone in Indiana.

In Indiana the Warsaw limestone crops out continuously from Montgomery County to Ohio River, with a thickness of 60–90 feet. It is divisible into two parts, the upper of which consists of 30–50 feet of massive regularly bedded pure limestone of light gray to bluish

gray color which weathers nearly white. Much of it is crystalline and certain layers are very fossiliferous. It contains some chert. At the top is a layer 4–10 feet thick consisting almost entirely of comminuted bryozoans.

The lower part has been separated into three members, the lowest of which, named Ramp Creek from a stream in Monroe County, is variable. It consists of brittle shaly, more or less siliceous, and sandy yellow-weathering limestone with local and irregular crinoidal lenses and attains a total thickness of 17–28 feet. It contains abundant geodes and much chert. The Leesville or middle member, named from a village in Lawrence County, is a massive resistant crinoidal limestone layer $1\frac{1}{2}$–8 feet thick and commonly crops out as an overhanging ledge and produces many small waterfalls. The upper or Guthrie Creek member consists of 2–10 feet of shaly to siliceous buff-weathering geode-bearing limestone. Its name is taken from a stream in Lawrence County.

The Warsaw limestone overlies the Edwardsville formation conformably in Indiana. The contact is fairly sharp and easily recognized throughout most of its extent in Indiana, but near Ohio River and southward in Kentucky, where the Edwardsville consists largely of limestone, their division becomes much more difficult.

OSAGE SEDIMENTATION

The almost complete transformation of the Osage group from a series of cherty limestones in the Mississippi valley to a series dominated by shales and sandstones in southwestern Indiana and the adjacent part of Kentucky is very striking. The records of deep wells indicate that this transformation occurs largely in the western part of the basin not far from the outcrop of these beds. In the oil fields of southeastern Illinois the Osage group consists of cherty limestone with shale at some horizons, and shaly zones also are present in an otherwise dominantly limestone Osage sequence in central Illinois.

On the east side of the Cincinnati arch, beds of Osage age make up the major portion of the Waverly series which resembles the Borden group of Indiana but contains more sandstone. In the southern part of the Appalachian region the Osage group is represented in the Fort Payne formation which, like the Osage beds of southern Illinois, is exceedingly cherty. These facts indicate that the clastic sediments were derived largely from the northern part of Appalachia, where evidently the land was much higher than it was in the southern part.

The Osage formations of Iowa give no indication of a near-by land area northwest of the Eastern Interior basin except during the final

Warsaw stage. Osage fossils are found in residual cherts widely scattered throughout the Ozark region and in weathered limestone boulders in the glacial drift of northern Illinois, giving evidence that the Osage sea spread far beyond the present outcrops of the group. However, the argillaceous content and red color of the Fern Glen formation in southwestern Illinois and the neighboring part of Missouri suggests that the Ozark region may not have been entirely submerged and perhaps was the source of some clastic sediment during early Osage time.

OSAGE PALEONTOLOGY

The faunas of the Osage formations are not sharply differentiated. They are, in reality, simply intergrading stages in a single slowly changing life succession. The Osage epoch was of sufficient duration that certain stocks underwent evolutionary changes, some old forms disappeared, and new ones were introduced. Large spiriferoids with high cardinal areas, such as *Syringothyris*, reached their culmination and other brachiopod forms attained unusually large size. *Leptaena analoga*, the last representative of an ancient stock, died out in early Burlington time. The *Spirifer grimesi-logani* gens which originated in Kinderhook time became conspicuous and abundant in the Burlington and Keokuk but did not continue later.

Some of the more typical species of the Fern Glen fauna are: *Cyathaxonia arcuata*, *Evactinopora sexradiata*, *Leptaena analoga*, *Dictyoclostus*[12] *fernglenensis*, *Productina sampsoni*, *Rhipidomella jerseyensis*, *Schizophoria poststriatula*, *Rhynchopora persinuata*, *Spirifer subtexta*, *Delthyris novamexicana*, *Spirifer rowleyi*, *Spirifer vernonensis*, *Brachythyris chouteauensis*, and *Cliothyridina glenparkensis*, although a number of these also occur in the lower part of the Burlington formation.

The Burlington limestone has been subdivided into a lower and an upper part largely on the basis of crinoids but these fossils are not sufficiently abundant or well enough preserved to be of much service except at scattered localities. Among the fossils restricted to the Burlington formation are *Cryptoblastus melo*, *Orbitremites norwoodi*, *Dictyoclostus burlingtonensis*, *Rhipidomella burlingtonensis*, *Camarophoria bisinuata*, *Spirifer grimesi*, *S. forbesi*, and *Spiriferella plena*. A number of older species which continued into Burlington but not

[12] Recent revision of the American Productidae has resulted in the removal of many species from *Productus* to several other genera including *Dictyoclostus*, *Echinoconchus*, *Linoproductus*, *Worthenella*, *Marginirugus*, and *Productina*. According to present interpretation the name *Productus* takes precedence over *Diaphragmus* and its use is now restricted to species formerly assigned to that genus.

into Keokuk time include *Leptaena analoga*, *Schizophoria swallovi*, and *Spirifer louisianensis*. New species which first appear in the Burlington but are also present in younger formations include *Triplophyllum dalei*, *Echinoconchus alternata*, *Brachythyris suborbicularis*, and *Reticularia pseudolineata*.

The Keokuk fauna contains bryozoans in much greater abundance and diversity than the Burlington fauna, and many new species appeared at this time. Two genera easily recognized and therefore particularly important are *Archimedes* and *Worthenopora*. Several new species of brachiopods developed in Keokuk time. The long-hinged *Spirifer logani*, which was apparently derived from the short-hinged *S. grimesi* of Burlington time and *S. rowleyi* of Fern Glen and early Burlington times, is characteristic of the Keokuk. *Dictyoclostus crawfordsvillensis*, which is confined to the upper part of the Keokuk formation, occurs in considerable numbers in Indiana, Kentucky, southern Illinois, and southeastern Missouri but is unknown north of St. Louis. *Spirifer logani*, *Orthotetes keokuk*, and *Tetracamera subtrigonia* are commonly associated with it. Species which first appeared in the Keokuk but continued into later epochs include *Orthotetes keokuk*, *Worthenella wortheni*, *Echinoconochus biseriata*, *Rhipidomella dubia*, *Camarotoechia mutata*, *Tetracamera subcuneata*, *Spirifer keokuk*, and *Eumetria verneuiliana*.

The paleontology of the Borden group in Indiana and Kentucky has never been studied systematically. The presence of numerous characteristic Mississippi Valley species shows the general equivalence of this group with the Osage group on the west but the great differences in environment in which the invertebrates lived on the two sides of the basin makes accurate correlation as yet impossible. The general equivalence of the New Providence to the Fern Glen is indicated by such diagnostic species as *Spirifer vernonensis*, *S. fernglenensis*, and *Ptychospira sexiplicata*. Equally characteristic Kinderhook species, such as *Schuchertella lenz* and *Athyris hannibalensis*, are present in the New Providence, however, and were they definitely restricted to the lower part this might be assigned to the Kinderhook. In Indiana and Kentucky there is no such sharp faunal break between the Kinderhook and Osage faunas as there is in the Mississippi Valley and thus the situation is somewhat similar to that of the Waverly series of Ohio, where such characteristic Kinderhook forms as *Promacrus* occur at least as high as the basal Logan, which has been variously correlated with the middle New Providence and Carwood of the Borden group.

The New Providence fauna, however, also contains species such

as *Brachythyris suborbicularis* and *Echinoconchus alternata* which are not known below the Burlington limestone of the Mississippi Valley, as well as an assemblage of crinoids characteristic of lower Burlington beds, but no fossils restricted to the upper Burlington have ever been reported from Indiana or Kentucky. The Kenwood sandstone, which is considered to be the topmost member of the New Providence formation, has yielded specimens of *Worthenella wortheni* which is unknown below the Keokuk limestone in the Mississippi Valley.

The Locust Point formation is almost barren of fossils other than worm markings but the Carwood fauna is distinctly Keokuk in age and contains such diagnostic species as *Orthotetes koekuk*, *Worthenella wortheni*, and *Syringothyris textus*. The Edwardsville fauna is dominated by Keokuk species, including *Rhynchopora beecheri* and *Spirifer crawfordsvillensis* in addition to those already mentioned, but also contains a few forms, such as *Spirifer washingtonensis*, which are not known below the Warsaw formation in the Mississippi Valley. *Archimedes*, which first appears and is common in the Keokuk limestone of Illinois, Iowa, and Missouri, is rare in the Edwardsville formation of Indiana and Kentucky and unknown at lower horizons.

The Warsaw and Salem faunas have been carefully studied and are well known. *Marginirugus magnus*, one of the largest American species of the Productidae, is restricted to an important zone in the upper part of the Keokuk and the lower part of the Warsaw formations. It is not known north of St. Louis but to the south and east it is widely distributed and locally extremely abundant. In association with it commonly occur *Syringothyris subcuspidatus*, *Spirifer washingtonensis*, and *Aviculopecten amplus*. *Brachythyris subcardiformis* has been reported from the Keokuk formation in Iowa but is not known to occur beneath the Warsaw formation in the Eastern Interior basin. The uncommon but very characteristic *Spirifer lateralis* is associated with this species in the Warsaw and Salem faunas.

Numerous new species appear in the Warsaw formation and practically all of the forms common in it occur also in the Salem formation. Among the more typical fossils that are confined to these formations are *Metablastus wortheni*, *Pentremites conoideus*, *Talarocrinus* (?) *simplex*, and *Archimedes wortheni*. Other common forms which survived into Chester time are *Dielasma inflatum*, *Girtyella indianensis*, *G. turgida*, and the typical form of *Composita trinuclea*. *Spirifer keokuk* is largely replaced in the Warsaw by the very closely related *S. bifurcatus*.

OSAGE-MERAMEC RELATIONS

The Osage group as characterized by the Burlington and Keokuk limestones and the Meramec group as typified by the St. Louis and

Ste. Genevieve are stratigraphic divisions easily distinguished by both paleontologic and lithographic characters throughout an extremely large area in the states east of the Mississippi River. Between these characteristic Osage and Meramec formations occur the Warsaw and Salem limestones, which are transitional beds, and the selection of a definite line of division is difficult and subject to much difference of opinion. At the present time this line is drawn by most geologists at the base but by some others at the top of the Warsaw, and the Illinois State Geological Survey has for some years followed the latter practice.

The Warsaw and Salem formations as now generally recognized are undoubtedly very closely related. Practically all of the common Warsaw fossils are known to occur in the typical Salem limestone of Indiana, and the latter formation is identified mainly by its oölitic character and a peculiar fauna in which small molluscs are conspicuous. The writers believe that neither the typical Salem lithology nor its peculiar fauna are of precise time significance but are reflections of more or less local environment conditions that prevailed in different areas at different times. Both are conspicuous in the Short Creek oölite of southwestern Missouri, which occurs in the basal part of the Warsaw formation, and in the so-called Salem limestone of Ste. Genevieve County, Missouri, whose upper part carries *Lithostrotion* and is therefore presumably of lower St. Louis age. Oölite carrying very similar molluscan faunas occurs in the Ste. Genevieve limestone, at several horizons in the Chester series, and even well up in the Pennsylvanian system of the Mid-Continent area.

Considerable difficulty and much uncertainty attends the identification of the Warsaw-Salem boundary wherever these beds crop out except in the Indiana area where the typical Salem limestone is developed, and nowhere else has the Salem formation been satisfactorily delimited. In western Kentucky and southern Illinois, Salem beds have not been differentiated and if they are present they have been included with the underlying Warsaw. In the Mississippi Valley area north of St. Louis there is strong reason to believe that the current Warsaw-Salem boundary, determined on the basis of a lithologic change no more significant than that which separates the Warsaw formation into lower and upper parts, is not drawn at an even approximately uniform horizon.

Under these circumstances the writers believe that the selection of the Warsaw-Salem boundary to separate the Osage and Meramec groups was unfortunate. They likewise believe that the restriction of the Warsaw formation, originally defined as including the beds between the Keokuk and St. Louis limestones, and the recognition

of the Salem formation in the Mississippi Valley was ill-advised. In their opinion the stratigraphic and paleontologic situation is best expressed by considering the Salem and underlying Harrodsburg limestones of Indiana as members of the Warsaw formation (72). With this interpretation (1) the name Warsaw would again be applied, as originally, to all beds between the Keokuk and St. Louis limestones, (2) it would be unnecessary to attempt to identify the Salem limestone in areas where its typical lithology is not developed, (3) the re-expanded Warsaw could be locally subdivided into members wherever desirable, (4) where warranted by lithology or other evidence the upper member would be correlated with the Salem limestone of Indiana, and (5) the Warsaw-St. Louis boundary would be the only alternative to the Keokuk-Warsaw boundary as the dividing line between the Osage and Meramec groups.

The Salem limestone is almost universally conceded to be a member of the Meramec group. Evidence concerning the proper disposition of the Warsaw is, however, conflicting. The facts that the limestone layers in the Warsaw formation are more or less granular, thus resembling those of the underlying Osage limestones rather than the dense limestone of the St. Louis, and that west of Mississippi River Warsaw strata are practically co-extensive with the underlying Burlington-Keokuk limestones rather than the more restricted St. Louis-Ste. Genevieve limestones[13] suggest that this formation should be included in the Osage group. The Warsaw fauna, which resembles the Keokuk fauna in many respects, has likewise been cited as evidence of the Osage age of this formation, but numerous new species appear in the Warsaw and, as previously noted, most of the common Warsaw species occur in the Salem limestone where the *Pentremites-Composita* fauna, so characteristic of all subsequent Mississippian formations, first becomes conspicuous. Furthermore the regional calcareous versus clastic composition of the Warsaw formation follows that of the overlying St. Louis and Ste. Genevieve limestones rather than the underlying Burlington and Keokuk limestones, as is discussed more fully elsewhere.

The writers believe that the Osage and Meramec groups should be separated at the boundary between the Keokuk and Warsaw forma-

[13] The recent discovery of limestone containing *Lithostrotion* (E. L. Clark, "The St. Louis Formation in Southwestern Missouri," *Mo. Geol. Surv.*, biennial report, 1937) and the occurrence of limestone of typical St. Louis lithology in the subsurface of northwestern Missouri (H. S. McQueen and F. C. Greene, "The Geology of Northwestern Missouri," *Mo. Geol. Surv.*, ser. 2, vol. 25, p. 31, 1938) has been brought to the writers' notice by H. A. Buehler. These occurrences prove conclusively that the Meramec sea was not as restricted to the west as was formerly supposed and consequently the argument presented above loses much of its force.

tions because they consider the very close relations of the Warsaw and Salem formations, as they are now commonly recognized, and the appearance of new species, including the characteristic *Pentremites-Composita* fauna, to be of more importance than the presence of many hold-over Keokuk species, and because they regard the continental physiographic changes, inferred from the regional sedimentological similarity of the Warsaw to characteristic Meramec rather than to characteristic Osage beds, to be of greater significance than the similarity in extent of the Warsaw sea in the Mid-Continent area to the preceding Osage rather than to the later Meramec seas.

MERAMEC GROUP

The Meramec group, named from Meramec River in Missouri, includes, according to the classification followed by the Illinois State Geological Survey, the Salem, St. Louis, and Ste. Genevieve limestones. As stated, the authors believe that the lower boundary of the group as thus defined is unsatisfactory and favor the inclusion also of the Warsaw formation.

Salem limestone.—Two names, Salem and Spergen, both taken from localities in Washington County, Indiana, have been applied to the limestone formation from which the famous Bedford, Indiana, building stone is obtained. The name Salem, which was proposed first and which has been used consistently by the Indiana Geological Survey for 30 years, is preferable to the name Spergen in spite of the fact that the latter has been adopted by the United States Geological Survey.

The Salem is characterized by massive cross-bedded light gray granular limestone composed almost entirely of fragments of fossils, the tests of foraminifera, and oölites. In its typical development in Indiana the Salem limestone is lenticular. It attains a thickness of 50–60 feet near Bedford but locally pinches out entirely. Layers of buff to nearly black bituminous calcareous shale are associated with the massive limestone, particularly at the top and bottom, and including these beds the formation reaches a maximum thickness of 90–100 feet. The same type of shale is present below the massive oölitic limestone throughout most of its extent in Indiana. Southward it becomes lighter in color and less bituminous and in Kentucky consists of 20 feet or less of shaly limestone or calcareous shale with interbedded layers of highly fossiliferous limestone which has been correlated with the Somerset shale member of the Warsaw formation in eastern Kentucky. Above this shale member south of Ohio River locally occurs a few feet of limestone which is stratigraphically equivalent

to the typical Salem limestone but lithologically indistinguishable from the Harrodsburg. This limestone has not been reported more than a few miles south of Ohio River.

In western Kentucky the Salem limestone, if present, has not been distinguished generally from the underlying Warsaw. Near Princeton, however, 40–50 feet of strata underlying the St. Louis limestone have been referred to the Salem. These beds were originally very pure limestone made up almost entirely of fragmental organic material but are now completely silicified although not changed to true chert.

In Hardin County, Illinois, the upper 60 feet or so of the "Warsaw" limestone may be equivalent to the Salem. They consist of light gray coarse-grained thick-bedded limestone with interbedded zones of darker shaly limestone and shale. In Union County, Illinois, the 200–250 feet of light-colored coarse-grained partly oölitic "Warsaw-Salem" limestone has not been subdivided.

In Ste. Genevieve County, Missouri, 160 feet of gray to white more or less oölitic limestone have been referred to the Salem, but paleontologic evidence strongly suggests that the upper part of these beds is actually of St. Louis age. The central 100 feet is an exceptionally pure oölite and is the basis of an important high-calcium lime industry. Northward the Salem limestone becomes progressively less pure. Oölite is present at Meramec Highlands west of St. Louis and near Alton, Illinois, but beyond this the formation as recognized consists mainly of earthy limestone with minor shaly and sandy beds.

At Warsaw, Illinois, beds referred to the Salem consist of 4–8 feet of more or less cross-bedded yellowish limestone that grade laterally into calcareous sandstone, which has been termed Sonora sandstone (27, p. 320). Apparently equivalent beds in southeastern Iowa attain a maximum thickness of nearly 30 feet, show a variable succession of cross-bedded crinoidal limestone, massive brown dolomitic limestone, brownish arenaceous dolomite, fine-grained bluish sandstone, and various types of shale which changes greatly from place to place, seem to overlie the subjacent Warsaw formation unconformably, and extend some distance beyond the limits of these beds. The name Belfast beds has been proposed for the Salem formation in Iowa (67, p. 214).[14]

Because the upper division of the Warsaw is similar to the overlying Salem beds and not easily separated from them, south of Warsaw the boundary between the two formations has been drawn at a horizon that more or less sharply separates a lower dominantly shaly zone (the lower division of the Warsaw) from an upper zone consisting of hard, massive to thin-bedded, granular to fine-grained, more or less

[14] This name has been previously used for a Silurian formation in Ohio.

earthy, impure and dolomitic limestone beds separated by layers or partings of shale that are commonly calcareous. The resulting "Salem" beds reach an average thickness of 60 feet in the area between Quincy and Alton, Illinois, although they may be considerably thicker locally. In Adams County, Illinois, a possible unconformity marked by basal conglomerate occurs in the midst of these beds and may be equivalent to the unconformity which occurs beneath the Salem in southeastern Iowa. In central Pike County, Illinois, Salem beds are reported to overlap older strata and rest on Burlington limestone (14, p. 93).

St. Louis limestone.—The St. Louis limestone was named from the city of St. Louis, Missouri, because of the many excellent exposures of the formation in that vicinity.

In southeastern Iowa the St. Louis is separated into two members, the Croton below and the Verdi above, both named from towns in Washington County. The Croton member consists of about 30 feet of compact buff dolomitic limestone which grades into or is interbedded with dense gray nondolomitic limestone. The Verdi member consists of a maximum of 35 feet of dense gray limestone which grades locally into fine sandstone. Both members are locally brecciated. The Croton member overlies older Mississippian strata unconformably and overlaps formations as low as the Kinderhook. It is separated from the Verdi member by another unconformity that is said to be recognizable as far south as Alton, Illinois (67, p. 231).

In western Illinois and northeastern Missouri the St. Louis limestone has not been separated from overlying beds that may be Ste. Genevieve in age. In Adams and Hancock counties, Illinois, and Lewis and Clark counties, Missouri, the lower 10–30 feet of St. Louis limestone is brecciated and conglomeratic, and the basal 2 or 3 feet is a nodular layer of dense crenulated limestone similar to that under the brecciated zones in Iowa. The brecciated horizon is less conspicuous to the south and is not present at the base of the formation in or beyond Lincoln County, Missouri. Above the brecciated layer the St. Louis formation is light gray dense, almost lithographic limestone in even layers locally separated by greenish calcareous shale. Local brownish dolomitic layers and more rarely sand lenses occur a short distance above the brecciated zone. Nodules and layers of chert are abundant. In Lewis and Clark counties, Missouri, the St. Louis is 40–60 feet thick. The upper part contains oölitic layers and a local sandstone as much as 6 feet thick and may represent the Ste. Genevieve formation. Farther south the St. Louis limestone is much thicker. At Alton, Illinois, it has been estimated to be 270 feet thick, and at

St. Louis its average thickness is said to be 325 feet, possibly including beds of Ste. Genevieve age. Still farther south, in Ste. Genevieve County, Missouri, beds assigned to the St. Louis limestone are 100–160 feet thick, but it is probable that a considerable portion of the 160 feet of oölitic limestone that has been referred to the Salem, an unprecedented thickness for that formation, is actually of lower St. Louis age. Throughout this area and also in Monroe County, Illinois, the St. Louis is mainly a compact dense gray limestone which breaks with a conchoidal fracture. Brownish dolomitic layers and beds of crystalline limestone occur locally, but shaly strata are few. Chert is common but not as abundant as in the Burlington and Keokuk formations. The St. Louis limestone is well and evenly stratified except where cross-bedded or brecciated. In southern Calhoun and Jersey counties, Illinois, there are several brecciated zones and a particularly conspicuous one occurs about 120 feet above the base of the formation at Alton. Similar zones have not been reported farther south. In southern Calhoun County beds of sandy oölite occur in both the lower and upper parts of the formation; possibly the upper oölitic beds should be referred to the St. Genevieve limestone.

The St. Louis limestone in Union County, Illinois, has an estimated thickness of 350–400 feet. The lower 25–30 feet is dense, dark gray, and siliceous; the middle part is dark gray and medium-grained with some interbedded coarser-textured strata; and the upper part is dark bluish gray and very dense with subordinate gray finely granular layers. Chert is abundant throughout the formation but is associated mainly with the denser strata.

In Hardin County, Illinois, and the neighboring portion of western Kentucky, the St. Louis is a dense fine-grained limestone with some granular and a few coarsely crystalline layers. The upper 75–100 feet is gray to bluish gray and the remainder is dark, nearly black limestone. Chert is common throughout and occurs mainly as irregular masses distributed parallel with the bedding. Some oölite occurs in the lower part of the formation near the Caldwell-Lyon county line southwest of Princeton, Kentucky. A deep well drilled near Princeton penetrated at least 300 and possibly more than 400 feet of St. Louis limestone.

Near Bowling Green in Warren County, Kentucky, the thickness of the St. Louis limestone penetrated in numerous oil wells is estimated at about 300 feet. At its outcrops in Barren and Warren counties the upper part of the formation is composed of dense gray limestone with some coarsely crystalline and some brownish lithographic layers; the middle part contains gray fine-grained closely banded

strata; and the lower part is characterized by black finely crystalline bituminous limestone with which are associated light gray to buff earthy dolomitic layers. The formation is cherty throughout but no oölite has been observed in this region.

The St. Louis limestone thins northward and probably does not exceed 300 feet anywhere in Hardin County, Kentucky. It consists of fine-grained gray to nearly black cherty limestone with some lithographic layers and some earthy siliceous geodiferous layers. The geode beds occur in the lower part of the formation as far as Rock Haven but have not been observed elsewhere. Lithographic stone has been commercially quarried near Brandenburg in Meade County, Kentucky.

In Indiana the St. Louis formation constitutes the lower part of the Mitchell limestone up to and including the Lost River chert member. The Mitchell limestone, which is named from a town in Lawrence County, includes the St. Louis, Ste. Genevieve, and Paoli (lower Chester) limestones. The St. Louis is mainly a dense sublithographic thin-bedded cherty limestone with interbedded shales, particularly in the lower 40 feet. The total thickness of the Mitchell is reported to be 200 feet in Monroe County but increases to 300 feet or more near Ohio River.

The St. Louis limestone weathers to a cavernous condition and its zone of outcrop is generally marked by many sink-holes. Although there is everywhere a more or less sharp change in lithology at the base of the St. Louis limestone, this formation succeeds the underlying beds conformably except along the northwestern border of the Eastern Interior basin. The St. Louis limestone passes more gradually into the overlying Ste. Genevieve and is conformable with it except along the western margin of the basin.

Ste. Genevieve limestone.—The Ste. Genevieve formation is typically exposed in the Mississippi River bluffs near Ste. Genevieve, Missouri. It is reported to be represented in the bluffs at Alton, Illinois, by 50 feet of fine calcareous sandstone but has not been certainly recognized farther north in Illinois. In southeastern Iowa the Verdi member of the St. Louis formation is overlain unconformably by the Pella beds of Ste. Genevieve age, named from a town in Marion County. The Pella beds consist of a thin basal sandstone, overlain by 5 feet of shale and 25 feet of compact thin-bedded limestone which grades into shale to the northwest.

In its typical area the Ste. Genevieve is a dark to light gray limestone which overlies the St. Louis unconformably at some places. A basal conglomerate contains limestone and chert pebbles and in Perry

County, Missouri, silicified Devonian fossils. At many places the lower beds are oölitic, arenaceous, and cross-bedded; higher strata are more regular and include a conspicuous band of reddish chert; and shaly beds, which are locally reddish, purplish, or greenish, and lenticular beds of fine-grained brown sandstone occur in the upper part of the formation at a few places. The thickness of the formation varies greatly from place to place as a result of pre-Chester erosion but may reach a maximum of 100 feet. Near Lithium in Perry County; Missouri, there is only 20 feet of Ste. Genevieve and the entire formation has been eroded from a considerable area in Monroe County, Illinois.

The Ste. Genevieve formation is about 300 feet thick in Union County, Illinois, and in Hardin County, Illinois, and in the neighboring portion of western Kentucky it averages about 250 feet with a maximum thickness of 320 feet penetrated by a well drilled near Princeton. It consists mainly of dense granular limestone in massive beds, some of which are oölitic and cross-bedded. Chert is not so abundant as in the underlying St. Louis limestone.

In the fluorspar district of southeastern Illinois and western Kentucky the Ste. Genevieve is divisible into three members: the Fredonia limestone, named from a village in Caldwell County, Kentucky; the Rosiclare sandstone, named from a mining town in Hardin County, Illinois; and the Levias (formerly Lower Ohara) limestone at the top, named from a village in Crittenden County, Kentucky (61, p. 439). The Fredonia limestone member includes the greater part of the formation. The Rosiclare is a brownish fine-grained calcareous sandstone 2 to 30 feet thick. It is not certainly known west of Pope County, Illinois, nor east of Cerulean Springs, Trigg County, Kentucky. Owing to pre-Chester erosion, the thickness of the Levias member ranges from 0 to 50 feet.

The thickest outcropping section of the Ste. Genevieve occurs in Union County, Illinois. A fine-grained calcareous sandstone 2–10 feet thick occurring 175 to 200 feet above the base of the Ste. Genevieve may represent the Rosiclare member. It is overlain by 30–40 feet of gray, granular, oölitic limestone, shaly in the upper part, that is probably the Levias member. This is succeeded by 50–80 feet of calcareous sandstone, limestone, oölite, and shale, some of which is red—these are believed to be the youngest Ste. Genevieve beds exposed anywhere in the Eastern Interior basin and for them the name Hoffner member is proposed as some of the best exposures of these beds occur near Hoffner School 7 miles southeast of Anna.

East of the fluorspar district in Kentucky the Ste. Genevieve

maintains a relatively constant thickness that is estimated at 180 feet in Edmonson County and 160 feet in Breckenridge County. The whole formation is similar to the Fredonia member farther west in Kentucky.

In Indiana the Ste. Genevieve limestone is represented by the middle part of the Mitchell limestone, above the Lost River chert. It is similar in color to the underlying St. Louis but is commonly oölitic and more heavily bedded.

The Ste. Genevieve is a cavernous limestone and like the St. Louis its presence is responsible for the development of large areas of karst topography. The lower passages of Mammoth Cave in Kentucky have been dissolved in the Ste. Genevieve limestone. Although it is not a notably cherty formation, numerous beds and irregular masses of chert do occur in it, particularly in the lower part, and chert is conspicuous in the residual soil derived from the Ste. Genevieve.

Except along the western margin of the basin the Ste. Genevieve succeeds the St. Louis conformably. At most places no sharp line of division can be drawn between these formations and it is common practice to place it more or less arbitrarily below the lowest prominent oölitic beds.

MERAMEC SEDIMENTATION

The Meramec group is the most uniformly calcareous and least clastic larger division of the Mississippian system in the Eastern Interior basin. At the close of the Keokuk epoch, as a result of either subsidence or erosion northern Appalachia no longer provided abundant sediment of the type that forms the greater part of the Borden group in Indiana. In the northwestern part of the Eastern Interior basin, however, clastic beds constitute an important part of the Meramec group and indicate the presence of a land area in that direction. The pre-Warsaw-Osage sediments of the upper Mississippi Valley yield little evidence of clastic material derived from the northwest and it is probable, therefore, that uplift occurred in this direction at the close of Keokuk time. This land area situated northwest of the Eastern Interior basin, however, was by no means as important a contributor of sediments during Meramec time as was northern Appalachia during Osage time.

MERAMEC PALEONTOLOGY

Practically all of the common Warsaw species are present in the Salem fauna but in addition there occurs a considerable variety of small molluscs which appear to be restricted to an oölitic limestone environment. These species, commonly associated with large numbers

of *Endothyra baileyi*, are indicative of certain special ecological conditions and are of no value for precise correlation. The assemblage first appears in the Short Creek oölite, which is the basal member of the Warsaw formation in southwestern Missouri, recurs in the Salem limestone of Indiana, in the so-called Salem near Ste. Genevieve, Missouri, which is probably in part of lower St. Louis age, and in the Ste. Genevieve limestone at various places. Very similar forms occur at several horizons in the Chester and even well up in the Pennsylvanian.

Although the St. Louis and Ste. Genevieve limestones are abundantly fossiliferous at many localities, it is so difficult to obtain identifiable specimens from these hard limestones that their faunas are the least adequately known in the entire Mississippian system, and no comprehensive and reliable list of species has ever been compiled for either of these formations. The faunas are too poorly known even to determine the upper limits of many Warsaw species. However, certain restricted species in the St. Louis and Ste. Genevieve are sufficiently abundant and conspicuous to identify certain faunal zones over wide areas. One of these, approximately equivalent to the St. Louis limestone, is marked by *Lithostrotion canadense*, an easily identifiable coral which is widely distributed and locally occurs abundantly in large colonies. It is readily silicified and is a common constituent of the St. Louis residuum. This species has never been observed anywhere in the Ste. Genevieve formation or in the Salem limestone of Indiana, and its occurrence, therefore, in beds near Ste. Genevieve, Missouri, which have been referred to the Salem on account of their lithology and molluscan fauna, suggests that these beds are at least in part of St. Louis age. A related form, *Lithostrotion proliferum*, has approximately the same range. It is unknown below the St. Louis formation but has been collected from beds referred to the base of the Ste. Genevieve in western Kentucky.

Platycrinus penicillus, a species of crinoid recognized by the small oval stem plates edged with spines, is of great importance in those regions where the lower formations of the Chester series consist of limestone, because it is widely present in the Ste. Genevieve limestone but has never been found in the Chester. This species also occurs in the St. Louis, however, and similar stem segments are present in the Salem limestone of Indiana. *Pugnoides ottumwa* which is locally abundant in Iowa but much rarer to the southeast occurs in the Fredonia, Levias, and Hoffner members of the Ste. Genevieve and is restricted to this formation. The compound coral *Lithostrotion harmodites* is conspicuous in parts of Kentucky, and in the western part of

the state it is restricted to a zone in the upper part of the Fredonia member.

The *Spirifer keokuk* gens continues throughout the Meramec group and is represented by the very closely related *S. bifurcatus* in the Salem, *S. littoni* in the St. Louis, and *S. pellaensis* in the Ste. Genevieve. This genus persisted into early Pennsylvanian time.

A few of the most common and characteristic Chester species, among which is *Productus elegans*, first appear in the Ste. Genevieve limestone but none of them is abundant.

MERAMEC-CHESTER RELATIONS

The unconformity which separates the Meramec group and the Chester series is the most important stratigraphic break within the Mississippian system in the Eastern Interior basin. It is not only actually exposed as an uneven contact between Meramec and Chester strata, but it is also demonstrated by local breccia and conglomerate beds in the basal Chester strata, by variation in thickness and absence of the upper members or all of the Ste. Genevieve formation within comparatively short distances, by overlap of Chester formations on older beds, by local variation in thickness of the basal Chester formations, and by other evidence.

In Ste. Genevieve and Perry counties, Missouri, the Ste. Genevieve limestone ranges in thickness from 20 to 100 feet or more. In Monroe County, Illinois, from T. 4 S., to T. 2 S., the basal Chester beds lie on the St. Louis limestone, the Ste. Genevieve limestone being absent except in the asymmetrical syncline which lies just west of the Waterloo anticline, although it is present both to the north in St. Clair County and to the south near the Randolph County line. In Secs. 5 and 8, T. 3 S., R. 9 W., southeast of Waterloo, Illinois, a hill of St. Louis limestone is bounded on three sides by the Aux Vases (basal Chester) sandstone. In the Mississippi River bluffs between Prairie du Rocher and Modoc, Randolph County, Illinois, the contact between the Ste. Genevieve limestone[15] and the Aux Vases sandstone dips more steeply than the limestone so that a number of the limestone beds are truncated. A conglomerate 2–3 feet thick is generally present at the base of the Aux Vases sandstone from Rock House Creek south for seven miles in Monroe County, Illinois, and also in the Mississippi River bluffs half a mile southeast of McBride in Perry County, Missouri. The chert pebbles in the conglomerate are identical with those derived from the St. Louis and Ste. Genevieve limestones and

[15] Recent observations indicate that these beds, referred to the Ste. Genevieve because of their oölitic nature, actually occur in the midst of the St. Louis limestone.

occurring along the present streams in this region. This indicates that these formations were thoroughly lithified and the nodular masses and beds of chert were developed in them before the beginning of Chester time.

Along a belt extending in Illinois from Sec. 30, T. 3 S., R. 9 W., south to the Monroe-Randolph county line the Renault formation, which overlies the Aux Vases sandstone unconformably and locally possesses a well developed basal conglomerate, overlaps both the Aux Vases sandstone and Ste. Genevieve limestone and comes to rest on the St. Louis. In Union County, Illinois, the Aux Vases sandstone is absent and the Renault formation lies on the Hoffner member of the Ste. Genevieve. The basal bed of the Renault is a nodular limestone, conglomeratic in appearance, and contains irregular masses of fine-grained sandstone and fragments of greenish shale.

In Hardin County, Illinois, the unconformable contact of the Shetlerville member of the Renault formation on the Ste. Genevieve limestone is well exhibited at Fairview Bluff above the railroad incline to a mine and also in the Ohio River bluff between Shetlerville and Wallace Branch, where a basal limestone conglomerate is present. A similar basal conglomerate 1 or 2 feet thick containing angular limestone pebbles up to 2 inches in diameter occurs at the base of the Renault at Cedar Bluff near Princeton, Caldwell County, Kentucky, and along the west side of Tow Hill and at Bissell Bluff northeast of Smithland in Livingston County, Kentucky. The Levias member of the Ste. Genevieve formation varies in thickness and is locally absent, as at a short distance northeast of Hampton and at Tow Hill, in Livingston County, and at several places northwest of Marion in Crittenden County, Kentucky.

In Warren and Edmonson counties, Kentucky, the exact contact of the Renault and Ste. Genevieve limestones has not been observed. The total thickness of the Girkin limestone (Renault and Paint Creek where the Bethel sandstone is absent), however, varies considerably, doubtless owing to the irregular upper surface of the Ste. Genevieve limestone on which it was deposited. Three or four miles west of Bowling Green this limestone is about 200 feet thick but only a few miles east it averages about 120 feet in thickness.

A basal conglomerate in the Renault formation has also been observed in a quarry on the Louisville, Henderson, and St. Louis Railroad, about one mile south of Sinking Creek in Breckenridge County, Kentucky, as well as at several other places in the same vicinity.

Although rarely exposed, the unconformity between the Ste. Genevieve and Paoli (lowest Chester) limestones in Indiana may be

TABLE

VARIATION IN THICKNESS OF CHESTER FORMATIONS. FIGURES IN ITALICS INDICATE AVERAGE OR COMMON DEVELOPMENT OF FORMATIONS

Name of Formation	*Dominant Character*	*Monroe, Randolph Counties, Illinois*	*Campbell Hill Quadrangle, Illinois*	*SE. Perry County, Missouri*	*Alto Pass Quadrangle, Illinois*	*Dongola Quadrangle, Illinois*	*Johnson County, Illinois*	*Pope County, Illinois*	*Hardin County, Illinois*	*Golconda Quadrangle, Kentucky*	*Cave in Rock Quadrangle, Kentucky*	*Smithland Quadrangle Kentucky*	*Eddyville Quadrangle, Kentucky*	*Princeton Quadrangle, Kentucky*	*Dawson Springs Quadrangle, Kentucky*	*Edmonson and Warren Counties, Kentucky*	*Meade and Breckenridge Counties, Kentucky*	*Indiana*
Kinkaid	Mainly limestone		90		0–50	?–50	?–140	?–150	?–100	?–200	0–125	?–160		100	100			0–20, 7[i] 15–40, *28*
Degonia	Sandstone		70–150		0–75	60–80	100	0–?	50–60	20–50	20	10–20		20–30	20			0–35, *10*
Clore	Mainly shale	60	40–70, *55*		20–40	10–40, *30*	40	?–40	25–30	30–60	25	?–40		30–60	50			10–35, *25*
Palestine	Sandstone	60–80	25–60, *45*		30	40–50	40–?, *60*	?–80, *60*	60–100	60	60	40–60	*50*	40–60	60–100	0–160[g]	30–274[i]	0–25, *5*
Menard	Mainly limestone	60–80			70–90	70–90	?–100	?–100	80–120[f]	80–100	100–140	80–100	100	?–140	55–80			15–45, *30*[k] 0–20, *4* 20–45, *30*
Waltersburg	Sandstone				20–40	30–40	0–?	?–70		30–40	20	20–35		6–20	0–3			0–40, *20*
Vienna	Shale and limestone	60–75[a]		?–30	20–30	30–40	*60*	40–70, *60*		30	30–40	35	30	50	12–40			0–125, *60*
Tar Springs	Sandstone			75–90	75	50–70	40–100, *80*	100–150	100–150	100–150	100–160?	?–120	?–100	200	?–200	0–30	5–50	0–90, *45*
Glen Dean	Mainly limestone		Ste. Genevieve and N. Perry Co. Missouri	75–90	30–40	60–80	40–75, *60*	*60*	50–70	60–80	50–60	60	60	?–90, *40*	40–80, *50*	30–70, *60*	40–90	0–40, *15*[l] 15–40, *15*
Hardinsburg	Sandstone	200[b]		0	20–40	?–50, *30*	30–100, *60*	80–100	75–100	100	100–140	100–120	?–100	20–60	40–60	30–40	20–35	25–45
Golconda	Mainly limestone		100–200	60–80	40–60	100–130	40–150	150	140	80–175	80–100	75–170	70	30–80	40–70	20–40, *35*	30–50	10–40[m] 15–25
Cypress	Sandstone	30–75[c]	0	0	30–50	60–120	80–100	80–100	80–110	100–125	*100*	100	*80*	30–40	25–40	40–75, *60*	40–70	30–45
Paint Creek	Mainly shale	60	50			30–50, *35*	?–60	35–60	40–50	20–40	20–40	0?–20	20	100	100	80–200[h]	60–90	10–30[n] 10–40 1–10
Bethel	Sandstone	10–20[d]	5–10[d]	80[e]	30–60[e]	?–12	0–30	0–130	50–60	60–100, *70*	*40*	?–120, *100*	40–75	25–40	30–40	0	5–40	20–30
Renault	Shale and limestone	20–60	45–90			70–90	50–60	60	75–90	60–100, *75*	20–100, *75*	80	40–80	60–100, *80*			60–70	5–20[o] 10–30 20–50
Aux Vases	Sandstone	0–100	40–60	55–105	0	0	0	0	0	0	0	0	0	0		0	0	0

[a] Baldwin formation. [b] Okaw formation. [c] Ruma formation. [d] Yankeetown chert. [e] Renault and Paint Creek formations. [f] Waltersburg and Vienna formations included in Menard. [g] Leitchfield formation. [h] Girkin formation (Renault and Paint Creek limestones). [i] Buffalo Wallow formation. [j] Negli Creek limestone and underlying shale. [k] Siberia limestone and over- and underlying shales. [l] Glen Dean limestone and overlying shale. [m] Golconda and Indian Springs formations. [n] Reelsville, Elwren, and Beech Creek formations. [o] Paoli, Mooretown, and Beaver Bend formations.

seen in a railroad tunnel about 1½ miles east of Depauw in Henderson County. This contact is commonly marked in Indiana by a brecciated or conglomeratic zone a few inches to several feet in thickness and at a few places is sharply defined and undulatory.

CHESTER SERIES

The Chester series is named from the city of Chester in Randolph County, Illinois. The section present in southwestern Illinois, however, is not typical of the series as a whole and the standard section has been built up mainly from studies conducted in Hardin County, Illinois, and adjacent portions of Illinois and Kentucky. No outcrops of Chester strata occur along Mississippi River north of East St. Louis, although they are present beneath the Pennsylvanian system in the Eastern Interior basin as far north as Macon County, Illinois. The northernmost outcrops of the Chester in Indiana occur in Putnam County, beyond which the series is completely overlapped by the Pennsylvanian system. South of these localities, however, the Chester formations crop out in a continuous band of varying width that outlines the Eastern Interior coal field.

The Chester series consists of a succession of alternating sandstone and limestone-shale formations of variable thickness and lithology (Table 1), none of which possesses physical characters by which it may be certainly identified over long distances. The sandstones resemble each other more closely than do the limestone-shale formations. They are all fine-grained, more or less micaceous, commonly iron-stained, and vary locally from massive to thin-bedded or shaly. With few exceptions, they can be identified only by their relations to the underlying and overlying formations. The sandstones generally rest unconformably on underlying beds.

The proportions of limestone and shale in the other formations vary greatly both laterally and vertically. The shales are either calcareous or noncalcareous but rarely contain arenaceous beds. They range from very plastic to hard, brittle, and closely laminated and possess all colors common to shale. The limestones are of all types except dolomitic, range from dense to coarsely crystalline or oölitic, and from purely calcareous to argillaceous or arenaceous, are commonly cherty only locally, are all shades of gray with reddish and greenish tints and some are stained brown, and may be massive or thin-bedded and shaly, evenly or irregularly bedded, cross-bedded, brecciated, or conglomeratic with rounded or angular pebbles of limestone and chert. Diverse types of shale and limestone are commonly present everywhere in each of these formations, and few of the char-

acters by which two formations may be differentiated at one place will serve the same purpose a few miles away. In areas where no faults exist, the various Chester formations may be traced laterally for considerable distances, but in faulted areas paleontology supplemented by local lithology and thickness is the only certain means of identification.

The large amount of shale in the Chester series favors slumping so that few outcrops exhibit more than a dozen feet of consecutive beds and formational contacts are rarely exposed. In most cases an exposure of a Chester section consists of outcrops of the more resistant sandstone and limestone layers separated by covered intervals representing the more shaly beds. The formations consisting principally of shale are rarely well exposed and at many places are indicated on the hillsides only by a terrace separating two sandstone formations. Because the sandstones are more resistant to weathering and erosion than are the limestone-shale formations they are not only more commonly exposed but beyond the glacial boundary they also control the topography and give rise to a series of cuesta-like ridges whose gentle back-slopes are the dip-slopes of the sandstones and on whose steep front-slopes the underlying limestone-shale formations crop out in narrow bands.

NEW DESIGN GROUP

The lower Chester group for which the name New Design is proposed consists of the Aux Vases, Renault, Bethel (or Yankeetown), and Paint Creek formations whose complete section occurs in outcrop only in Monroe and Randolph counties, Illinois, and the adjacent part of Missouri. The group is named from New Design township in Monroe County, Illinois, where all four formations are well developed.[16]

Aux Vases sandstone.—The oldest formation of the Chester series is named from Aux Vases River in Ste. Genevieve County, Missouri, and is well exposed in the adjacent Mississippi River bluffs. It is present in outcrop only from southern St. Clair County, Illinois, to southeastern Perry County, Missouri; it is the basal member of the Chester series except locally in the southern half of Monroe County where it is overlapped by the Renault formation. It varies greatly in thickness because it was deposited on an uneven surface of the Ste.

[16] Cumings (16, p. 514 footnote) has suggested but not formally proposed the Indiana names West Baden and Stephensport for the lower and middle Chester groups. The writers, however, consider it advisable to select names from other areas where the Chester stratigraphy has been studied in greater detail than it has in Indiana.

Genevieve and St. Louis limestones and also because it suffered erosion before the deposition of he Renault formation.[17]

In Illinois the Aux Vases sandstone is brownish fine-grained massive cross-bedded sandstone. In Missouri more or less variegated shaly beds occur in both the upper and lower parts of the formation and the middle massive sandstone is more yellowish than in Illinois. In Perry County, Missouri, the Aux Vases is coarser-grained and resembles the St. Peter formation locally, but the sand grains are commonly neither well rounded nor frosted. A basal conglomerate is present at many places in both Illinois and Missouri.

Renault formation.—The Renault formation is named from Renault Township, Monroe County, Illinois, in the eastern part of which it is well exposed along the two forks of Horse Creek. In Monroe and Randolph counties, Illinois, this formation includes sandstones, variegated arenaceous and calcareous shales, and limestones. Most of the limestone layers are greenish, dense, and arenaceous, but others are bluish gray, crystalline and pure, or argillaceous and shaly, and rarely oölitic. At many places the sandstones are flaggy and pierced by worm borings, and in the upper part of the formation are massive beds of sandstone which closely resemble the Aux Vases except that they contain numerous casts of *Lepidodendron* that are unknown in the lower formation.

The Renault is much the same in Ste. Genevieve County, Missouri, but on the south limestone beds become more conspicuous and the sandstones are absent. In the upper part of the formation one limestone which is 12 feet thick near the mouth of Saline Creek increases to 50 feet near St. Mary. Locally in the southern half of Monroe County, Illinois, the Renault overlaps the Aux Vases sandstone and becomes the basal member of the Chester series. A basal conglomerate containing pebbles of limestone and chert, and fragments of igneous rock at one place in Ste. Genevieve County, occurs at many localities in Missouri and in Monroe County, Illinois.

In southeastern Perry County, Missouri, and western Union County, Illinois, the Renault and Paint Creek formations have not been differentiated. In eastern Union County the Renault is composed mainly of limestone but contains some shale. The limestone is commonly light gray and dense but some beds are dark; some are more crystalline and crinoidal, and some are oölitic. The shale is mostly gray or greenish gray and more or less calcareous but some of it is

[17] Recent observations suggest that the basis for separating the Aux Vases and Renault formations is not so convincing as has previously been supposed and that the Aux Vases may be sandstone filling pre-Chester channels and therefore might be considered simply the local basal member of the Renault formation.

dark red. A nodular limestone interpreted as a basal conglomerate has been observed at one place.

In Johnson, Pope, and Hardin counties, Illinois, and adjacent parts of Kentucky, the Renault formation is divisible into two members which are locally unconformable. The lower or Sketlerville member is typically developed in Hardin County, Illinois, where it is about 30 feet thick but it thins and becomes indistinguishable both to the west and to the southeast. It consists mainly of calcareous shale with interbedded dark gray crystalline cross-bedded limestone. The upper member is composed of gray to bluish gray dense or crystalline limestone, some of which is oölitic and cross-bedded and more or less cherty in the upper part. The limestone beds are separated by partings or thin beds of calcareous shale. Farther east in Kentucky the shaly layers of the Renault formation become less conspicuous and it consists of a limestone that can not be distinguished from the Paint Creek formation where the Bethel sandstone is absent.

In Meade and Breckenridge counties and adjacent areas in Kentucky the Renault consists predominantly of limestone much of which is oölitic. Locally a bed of dark gray siliceous oölite containing fine quartz grains occurs in the lower part of the formation. This is underlain by a 2-foot layer of limestone conglomerate which rests directly on the Ste. Genevieve limestone. Some shale beds are present in the Renault in this area and the sandstone which is so conspicuous in the middle part of the formation farther north in Indiana is represented by a thin sandstone locally occurring at the base of the formation and elsewhere up to 28 feet above the base. This sandstone is not known south of Spurriers Mills and thickens gradually to the north. Locally it is developed in channels to a thickness of as much as 75 feet. At several places a thin seam of coal with underclay is associated with this sandstone.

The Renault formation in Indiana consists of three members named in ascending order Paoli, Mooretown, and Beaver Bend.[18] The upper and lower members consist of massive oölitic limestone, the lower of which constitutes the upper part of the Mitchell limestone. These are separated by the well defined Mooretown shale and sandstone member which contains very massive beds locally, as near New Amsterdam where it forms a conspicuous ridge overlooking Ohio River, and locally carries a thin seam of coal near Bloomington. It is possible that the horizon of this sandstone is represented in Hardin County, Illinois, by the unconformity that has been observed locally

[18] These and the following correlations of the Chester formations of Indiana, except where noted to the contrary, are suggested by Malott.

above the Shetlerville member, and that the Shetlerville and Paoli members are equivalent.

Yankeetown chert.—Although the Yankeetown chert, named from Yankeetown school in Monroe County, Illinois, is only 5–20 feet thick, it is a remarkably persistent formation in Monroe and Randolph counties, Illinois, and Ste. Genevieve County, Missouri. In outcrops it is composed of chert, arenaceous chert, quartzite, and hard siliceous limestone with a few thin local beds of shale. The chert and quartzite are commonly rose-colored and the chert is generally irregularly banded. The cherty character of this formation is probably largely surficial and related to weathering, because wells which pass through it encounter only sandstone at the Yankeetown horizon. The Yankeetown chert is believed to be unconformable on the Renault formation because it rests on various upper Renault beds and because the thickness of the Renault formation is so variable.[19]

Bethel sandstone.—In southern Illinois and western Kentucky the Yankeetown chert is represented by the Bethel sandstone, named from Bethel school, $3\frac{1}{2}$ miles west of Marion, Crittenden County, Kentucky. Unfortunately the sandstone that is conspicuously exposed at this locality and that, therefore, might on casual examination be thought to be the Bethel is the lower part of the Cypress, talus from which almost completely covers the underlying Paint Creek and true Bethel formations.

The Bethel sandstone is a brownish moderately fine-grained sandstone, in part massive and cross-bedded and in part more thinly and evenly bedded. It is as coarse or coarser than the other Chester sandstones, at a few places it contains small quartz pebbles, and locally it is conglomeratic at the base. It lies unconformably on the Renault formation.

In Union County, Illinois, the Bethel sandstone is nowhere more than 10 feet thick. In the western part of the county and in southeastern Perry County, Missouri, it can not be recognized with sufficient certainty to separate the Renault and Paint Creek formations. In southern Johnson County, Illinois, it reaches a maximum thickness of 12 feet but is apparently absent at some places. To the east it thickens to 50 feet in the Ohio River bluff below Golconda, and on both sides of the river near Shetlerville it is at least 100 feet thick. Southeastward in Kentucky it thins. In the vicinity of Marion and Princeton it is represented by 25 to 40 feet of strata but has not been

[19] Recent observations suggest that the Yankeetown chert is in part the upper weathered portion of the Renault formation that extends downward to different horizons at different places.

recognized beyond Taylor's Chapel, about $2\frac{1}{2}$ miles west of Elkton, Todd County.

On the east side of the coal field in western Kentucky the Bethel sandstone is again present and has been called the Sample sandstone from Sample in Breckenridge County. It is a variably developed flaggy to shaly sandstone uniformly present in Meade, Breckenridge, and Ohio counties and extends into Hardin and Grayson counties, although the formation thins and is absent a short distance south of Millerstown.

The Bethel sandstone occurs persistently in Indiana, where it has also been called Sample. It is represented locally by massive beds but in certain areas it is shaly.

Paint Creek formation.—The Paint Creek formation is named from Paint Creek in Randolph County, Illinois. In Monroe and Randolph counties, Illinois, and northern Perry County, Missouri, it uniformly consists of calcareous shale and interbedded limestone with a conspicuous dark red non-laminated clay 12 to 15 feet thick about 10 feet above the base. In the lower part of the formation shale predominates and the limestone beds are argillaceous and separated by numerous bluish shaly partings, but higher in the formation the limestone layers are more massive, purer, and crystalline, and at the top is a limestone bed about 10 feet thick.

In southeastern Perry County, Missouri, and western Union County, Illinois, the Renault and Paint Creek formations have not been separated. Although their total thickness is nowhere more than 80 feet and locally as little as 30 feet, the faunas indicate that both formations are present. They consist of shale, portions of which are variegated purple, yellow, and red, and of limestone, some of which is quite sandy.

Where the Bethel sandstone is recognized, so that the Renault and Paint Creek formations can be separated, the Paint Creek formation consists mainly of soft dark noncalcareous shale. Purplish sandy limestone, limestone conglomerate containing pebbles up to two inches in diameter, and lenses of irregularly bedded ripple-marked fine-grained calcareous sandstone containing shale pebbles occur at several horizons in the formation.

In southern Johnson County, Illinois, the lower portion of the Paint Creek formation is composed mainly of shale which grades upward into alternating limestone and shale. In western Hardin County, Illinois, it consists largely of dark laminated shale with local thin beds of sandstone or siliceous limestone, and where present in the eastern part of the county, it is mainly thin-bedded sandstone.

In Livingston and Crittenden counties, Kentucky, the Paint Creek formation is much the same as in Pope and Hardin counties, Illinois. To the southeast this formation becomes thicker and contains more limestone. In Caldwell County both the upper and lower parts consist of massive crystalline locally oölitic limestone beds separated by shaly partings, whereas the middle part of the formation is shaly. At some places a thin sandstone is present near the top of the Paint Creek formation. At the Caldwell-Christian county line this formation is almost entirely limestone.

Farther east along the southern border of the western Kentucky coal field the Bethel sandstone is absent and the Renault and Paint Creek formations can not be readily separated. In Meade, Breckenridge, Ohio, and parts of Hardin and Grayson counties, Kentucky, the Bethel sandstone is again present in the section and the Paint Creek formation consists of five rather variable members. Three of these, the lowermost, middle, and uppermost members, are composed largely of shale and the two intermediate members are somewhat massive limestones. Clastic beds reappear more abundantly in the Paint Creek formation to the north. In Indiana the formation contains three named members: the Reelsville limestone at the base, the Elwren sandstone and shale in the middle, and the Beech Creek limestone above. Both of the limestone members are more or less oölitic. The Elwren member commonly consists of two layers of sandstone separated by shale and has been traced as far south as Girkin in Warren County, Kentucky.

Girkin limestone.—From Todd County to Grayson County, Kentucky, the Bethel sandstone is absent and the Renault and Paint Creek formations together form a limestone unit that can not be easily subdivided. The name Gasper has been used for this limestone, but persistent miscorrelation has resulted in such confusion that the name is no longer useful. Consequently, these beds are now known as the Girkin limestone, named from a village in Warren County, Kentucky (61, p. 441).

The Girkin formation consists almost entirely of massive light gray limestone which can not be distinguished from the underlying Ste. Genevieve except by its fossil content. Some parts of the formation are highly oölitic and conspicuously cross-bedded, and such layers are extensively quarried for building stone near Bowling Green. The Girkin limestone is very susceptible to solution by ground water and has given rise to large areas of karst topography. The upper levels of Mammoth Cave are developed in it. Locally, gray shale as much as 20 feet thick is present at the top of the formation.

NEW DESIGN PALEONTOLOGY

Marine fossils in the New Design group are confined to the Renault and Paint Creek formations whose faunas are very closely related. They are characterized by the crinoid *Talarocrinus* and the bryozoan *Cystodictya labiosa*, which are restricted to these beds except that *Talarocrinus* (?) *simplex*, a form distinct from the Chester species, occurs in the Warsaw and Salem formations. *C. labiosa* is more common in the Paint Creek formation than in the Renault but specimens of *Talarocrinus* are generally more abundant in the Renault than in the Paint Creek.

The Shetlerville member of the Renault formation in southeastern Illinois and western Kentucky is abundantly fossiliferous and three species—*Spiriferina subspinosa*, *Talarocrinus buttsi*, and *Globocrinus unionensis*—are restricted to it. The coral *Amplexus geniculatus* is also very characteristic of this member and has not been certainly recognized elsewhere, although the same or a closely related form occurs rarely as high as the Glen Dean limestone. Of these four species only *T. buttsi* has been collected from the Renault formation farther east, where the basal part of the formation is largely limestone.

Pentremites with the "pyriformis" type of elongated bases occurs first in the Renault formation, and at many places the bases of *Lyropora* are abundant. Although *Archimedes* is conspicuous in most of the higher faunas it is rare in the Renault formation and only one species, *A. invaginatus*, is locally common.

In the Paint Creek formation *Pentremites* occur in great numbers and variety, and forms with concave ambulacral areas become common for the first time. *Archimedes* also becomes abundant and *A. compactus* is particularly characteristic of this formation, although it recurs rarely at higher horizons. *Glyptopora punctipora*, which also occurs in the Renault formation, is common at many places but is rarely found higher. *Pterotocrinus* first appears in the Paint Creek formation. *Chonetes chesterensis*, which is very unusual in other Chester formations, is locally common. *Spiriferina spinosa* is much more abundant than *S. transversa* in the Paint Creek fauna. *Camarotoechia purduei* is rare and is known only in the Paint Creek formation in the Eastern Interior basin.

HOMBERG GROUP

Although the original subdivision of the Chester series was made in southwestern Illinois, later studies showed that the lithology of the middle Chester group changed notably to the southeast, and because the formations recognized in Hardin County and the adjacent parts

of Illinois and Kentucky are more uniformly and widely developed, their succession in this area has been adopted as standard. It is possible that restudy may reveal the applicability of the standard classification to the southwestern Illinois section, but at present it is necessary to describe the formations in each area separately.

The name Homberg is proposed for the middle Chester group and is derived from the village of Homberg in Pope County, Illinois, near which it is well and typically developed. It includes the Cypress sandstone, the Golconda limestone, the Hardinsburg sandstone, and the Glen Dean limestone of the standard succession.

Cypress sandstone.—The Cypress sandstone, named many years ago from exposures on Cypress Creek in Johnson County, Illinois, is the most persistently thick and massive sandstone of the Chester series along the southern and eastern margins of the Eastern Interior basin. It thins notably westward, however, in northern Union and southern Jackson counties, Illinois, and is absent in Perry County, Missouri. In Randolph County, Illinois, the Cypress sandstone is represented in the Ruma formation.

The Cypress is generally a massive cross-bedded cliff-forming sandstone that weathers brown; it overlies the Paint Creek formation unconformably. Along the southern margin of the basin the lower part of the formation is more massive and is succeeded by thinner-bedded sandstone and shale that grade into the overlying Golconda formation. In Crittenden and Livingston counties, Kentucky, the middle part of the Cypress formation includes carbonaceous shales and a discontinuous coal bed which reaches a thickness of 4 feet at one or two places and was formerly mined. Another thinner but more persistent coal bed is present between the Cypress and Golconda formations in Edmonson, Grayson, and possibly also in neighboring counties, Kentucky.

In Christian and Caldwell counties, Kentucky, the Cypress consists chiefly of thin-bedded sandstone and shale but farther east in Warren County it is the most massive and thickest sandstone in the Chester series in that area. To the north along the eastern border of the basin in Kentucky the Cypress includes much shale and locally consists almost entirely of shale. In southwestern Indiana it is commonly a massive sandstone but locally it is composed almost wholly of shale.

Golconda limestone.—The Golconda limestone, named from the city of Golconda in Pope County, Illinois, succeeds the Cypress sandstone conformably. It constitutes the lower part of the Okaw formation in southwestern Illinois and is the highest Mississippian

formation in northern Perry County, Missouri, where it is represented by gray crystalline limestone which overlaps the Ruma and rests unconformably on the Paint Creek formation. Conglomerate composed of small angular limestone and chert pebbles occurs locally in the lower part.

In southeastern Perry County, Missouri, and in Jackson County, Illinois, the Golconda formation consists of massive crystalline limestone interbedded with shale. Some of the limestone is sandy and cross-bedded.

In eastern Union County, Illinois, the formation consists of an upper and a lower limestone separated by shale. The limestones are gray and granular with partings and beds of shale and with some oölite locally. The shale of the middle member is both argillaceous and calcareous and contains thin lenticular limestone layers. The three-part division of the Golconda continues some distance to the east but the shale content of the entire formation is variable, ranging from 50 to 90 per cent.

The Golconda formation attains its maximum development in Livingston County, Kentucky, where it consists of a variable succession of shales and limestones, the latter occurring more commonly in the upper part of the formation.

In Warren, Edmonson, and Grayson counties, Kentucky, the Golconda formation is mainly heavy-bedded gray limestone with some gray shale at the base and locally also at the top. Northward along the eastern border of the Eastern Interior basin it consists of a lower locally variegated shale 15–30 feet thick and an upper limestone about 30 feet thick. In Indiana the lower shale has been named Indian Springs[20] and consists of blue-gray to olive-green argillaceous beds. The overlying limestone to which the name Golconda has been restricted in Indiana is coarse, semi-crystalline, and locally oölitic. Chert, which is practically absent from all of the other Chester formations in Indiana, is abundant in this formation at many places as far south as Breckenridge County, Kentucky.

Hardinsburg sandstone.—Excepting the Cypress, the Hardinsburg is the most persistently thick and massive sandstone of the Chester series. It is named from Hardinsburg in Breckenridge County, Kentucky, and attains its maximum development near Marion in Crittenden County, Kentucky. Like the Cypress, it thins westward in northern Union and southern Jackson counties, Illinois, and is absent

[20] Malott correlates this shale with the upper part of the typical Cypress sandstone, but its character and the relative thickness of the underlying sandstone and overlying limestone indicate that it is probably the lower part of the Golconda formation.

from the Chester section in southeastern Perry County, Missouri. It is probably represented in Randolph County, Illinois, by the chert horizon in the middle of the Okaw formation.

The Hardinsburg sandstone overlies the Golconda formation unconformably. Considerable shale is present in the Hardinsburg and the proportions of shale and sandstone vary greatly from place to place. Although locally it forms conspicuous cliffs, its massive beds are generally friable and its thinner beds are shaly. In Livingston County, Kentucky, a coal bed is locally present in a shale zone in the middle of the formation. The Hardinsburg grades conformably through shales into the overlying Glen Dean limestone.

Glen Dean limestone.—The uppermost formation of the Homberg group is named from the village of Glen Dean in Breckenridge County, Kentucky.

As indicated by fossils, the Glen Dean limestone is represented in the Okaw formation of Randolph County, Illinois, and in the Chester sections of southwestern Jackson County, Illinois, and southeastern Perry County, Missouri, but it can not be satisfactorily separated from the underlying Golconda formation because the Hardinsburg sandstone is absent.

The Glen Dean formation consists of gray to buff, coarsely to finely crystalline, more or less sandy and irregularly bedded limestone and intercalated shale, some of which is locally highly colored. Shale is most abundant in the upper part of the formation and is mainly calcareous, although arenaceous beds are locally present. Conglomerate containing subangular chert pebbles has been observed, and one or more local disconformitites may occur within the formation.

In Union County, Illinois, the lower portion of the Glen Dean formation is mainly shale with some interbedded limestone and the upper part is mainly limestone with some interbedded shale. Most of the limestone is gray, moderately coarsely crystalline, massive, and crinoidal, but some of the more ferruginous layers weather buff. Dense beds are locally present, and a prominent oölite layer occurs near the top of the formation.

In Pope and Hardin counties, Illinois, and Livingston and Crittenden counties, Kentucky, shale generally predominates in the lower and limestone in the upper part of the Glen Dean, but the formation is quite variable and this situation is locally reversed. The limestones are generally gray, crystalline, and more massive than those of the Golconda, but there are some dense beds, some highly siliceous limestones are locally present near the base, some nearly black limestones have been noted, particularly in Hardin County, and at a number of places an oölite bed occurs near the top. The Glen Dean formation

contains some chert, although not nearly as much as do some of the higher Chester limestones. Sinkholes are locally developed in this formation. In Caldwell and Christian counties, Kentucky, the Glen Dean is largely shale with some interbedded limestone, especially in the upper part of the formation. At some places a hard dense limestone as much as 10 feet thick forms the base of the formation, and a sandstone as much as 9 feet thick is locally present in its midst.

Farther east along the southern border of the Eastern Interior basin the Glen Dean formation contains more limestone, and in Warren and Edmonson counties, Kentucky, it is mainly massive thick-bedded limestone, very similar to the Golconda, with a thin basal shale member. In Breckenridge County, Kentucky, and adjacent areas it possesses a lower and an upper shale member and a central limestone member which is divided into two parts by a shale zone near the middle. The limestone is generally conspicuously light-colored, crystalline, and crinoidal and contains some beds of oölite. The shales are commonly bluish but locally may contain greenish and reddish layers in both the lower and upper members. In Indiana the Glen Dean limestone is thick-bedded, massive, and more oölitic than any other Chester formation in that state.

Ruma formation.—In Monroe and Randolph counties, Illinois, the Paint Creek formation is succeeded with apparent conformity by the Ruma formation, named from a village in northern Randolph County near which it is well exposed in the tributaries of Horse Creek. The Ruma formation is locally 75 feet thick in Illinois but is entirely absent west of Mississippi River. It consists principally of shale with considerable interbedded sandstone, and a thin limestone member is locally present. The middle part of the formation is the most arenaceous and contains thin-bedded sandstone and sandy shale, but at some places similar beds are present in the upper part of the formation. Some of the sandstone is ripple-marked, and casts of *Lepidodendron* are abundant at a few places. The shaly strata are characteristically variegated and contain reddish and purplish beds similar to some of the Renault shales in this same region. Conspicuously variegated shales occur in no higher Mississippian formation in southern Illinois except the Kinkaid, in which they are only locally developed.

The Ruma formation is approximately equivalent to the Cypress sandstone of southeastern Illinois and western Kentucky.

Okaw limestone.—The Okaw formation was named from Okaw (Kaskaskia) River in Randolph County, Illinois. As originally defined it included all strata between the Ruma formation and the Menard limestone in Randolph County, Illinois. For many years the formation has been informally subdivided into upper and lower Okaw

beds that were commonly correlated with the Glen Dean and Golconda formations of the Ohio Valley. It has recently been determined, however, that the upper Okaw consists of strata equivalent to the Tar Springs sandstone, Vienna limestone, and Waltersburg sandstone of the standard section (59). Because the formation as originally defined transgresses the boundary between middle and upper Chester groups, and because the old upper Okaw is a mappable unit, it is now proposed that the name Okaw be restricted to the old lower Okaw beds and the name Baldwin formation be used for the beds of upper Chester age formerly classed as upper Okaw.

The Okaw formation as thus restricted consists of about 200 feet of limestones alternating with shales, both types of strata being variable. The limestones are commonly light gray in color and many strata are more or less crystalline. A cherty zone 10 feet or less thick occurs in the middle of the formation and is believed to mark the horizon of the Hardinsburg sandstone just as, in this same region, the Bethel sandstone is represented by the Yankeetown chert. This chert horizon has not been recognized throughout the extent of the Okaw formation and may not be persistent, so that Golconda and Glen Dean beds can not be consistently separated. Chert elsewhere in the formation is practically absent. Many of the limestones in the lower half of the Okaw are more or less oölitic and one conspicuous oölite, the Marigold member, which is well exposed near the village of that name, occurs about 75 feet above the base. Above the chert horizon oölites are generally absent but here, particularly at the very top of the formation, occur the most massive limestone beds.

HOMBERG PALEONTOLOGY

One of the most important fossils which first appears in the Homberg or middle Chester group is *Camarophoria explanata*. This little brachiopod has been collected from the Cypress sandstone both in southern Illinois and western Kentucky, is present almost everywhere in the Golconda limestone, and persists in all of the higher Chester limestones. The most important fossil that is restricted to the Golconda formation is *Pterotocrinus capitalis*, whose wing plates characterize the lower part of the formation from Johnson County, Illinois, to Christian County, Kentucky. Associated with this species is the rarer but equally distinctive *Pentremites obesus*, which is the largest known species of the genus. Other fossils which so far as known are confined to the Golconda include *Rhynchopora perryensis*, *Archimedes lativolvis*, and a largely undescribed assemblage of Salem-like molluscan species.

The fauna of the Glen Dean formation is rich in bryozoans at many localities. The two most important species are *Prismopora serratula* and *Archimedes laxus*. In the southeastern tip of the Eastern Interior basin these forms are also abundant in the Golconda formation but are unknown in that formation farther west in Kentucky or in southern Illinois. *Prismopora* recurs less commonly in the Vienna and more rarely in the Menard faunas. Four other species which are believed to be almost exclusively confined to the Glen Dean are *Pentremites spicatus*, *Pterotocrinus bifurcatus*, *P. acutus*, and *Cheilotrypa hispida*. *P. spicatus*, however, occurs in southwestern Illinois in beds of Vienna age in the Baldwin formation.

ELVIRA GROUP

The name Elvira, derived from a township in Johnson County, Illinois, where all of the formations of the standard section are well developed, is proposed for the upper Chester group. This group consists of eight alternating sandstone and limestone-shale formations, namely, the Tar Springs sandstone, the Vienna limestone, the Waltersburg sandstone, the Menard limestone, the Palestine sandstone, the Clore limestone-shale, the Degonia sandstone, and the Kinkaid limestone. The sandstones, which are similar to those in the New Design and Homberg groups, are best developed in southern Illinois and the adjacent part of western Kentucky. Toward the southeast they become thin and shaly and can not be recognized in the extreme southeastern part of the Eastern Interior basin. In comparison with the limestones of the New Design and Homberg groups, the limestones of the Elvira group are generally finer-grained and darker-colored, have fewer light gray crystalline beds, are somewhat siliceous, contain abundant chert at some horizons, commonly weather to smooth hard surfaces without crumbling, and generally possess uneven hummocky bedding planes. The limestone strata of the Elvira group thin and become shaly to the southeast and in the southeastern part of the basin the entire Elvira group consists mainly of shale which has not yet been subdivided into the standard formations.

Tar Springs sandstone.—The Tar Springs formation, which receives its name from a locality 3 miles south of Cloverport in Breckenridge County, Kentucky, is one of the thicker and more persistent sandstones of the Chester series. It is probably represented by the arenaceous beds in the lower part of the Baldwin formation in Monroe and Randolph counties, Illinois. From southeastern Perry County, Missouri, to Warren County, Kentucky, the Tar Springs sandstone generally consists of lower and upper massive parts separated by a

shaly zone that is commonly carbonaceous and locally contains a thin bed of coal. In Caldwell and Christian counties, Kentucky, it has the greatest development of any Chester sandstone in the Eastern Interior basin. East from Warren County, Kentucky, and north along the eastern border of the basin the Tar Springs sandstone is erratically developed and may consist of either massive or shaly beds or may be locally absent.

Vienna limestone.—The Vienna formation, which is named from Vienna in Johnson County, Illinois, is one of the thinner limestone-shale formations of the Chester series. It is probably represented in Randolph County, Illinois, by the shale and limestone beds in the middle of the Baldwin formation. It is the youngest Chester formation in Missouri, where it is represented by thick residual chert on a few hill tops in southeastern Perry County. The Vienna formation persists across southern Illinois and as far as eastern Christian County, Kentucky, although it has not been distinguished from the Menard formation in Hardin County, Illinois.

The Vienna formation is somewhat variable, but the lower part is dominantly limestone and the upper part dominantly shale. The limestone is mainly fine-grained and bluish gray to nearly black, in beds one foot or less thick, some of which weather to light brown, spongy masses. Much dark-colored chert occurs in layers 1 to 3 inches thick. The shales are bluish gray to black except locally in southern Crittenden County, Kentucky, where some reddish layers are present. A few inches of coal occur in Pope County, Illinois, about 4 feet below the limestone. In northeastern Christian County, Kentucky, there are no limestone beds in the Vienna formation and it has not been differentiated farther east.

In Breckenridge and Ohio counties, Kentucky, the Tar Springs sandstone is overlain by a persistent limestone layer, rarely more than 10 feet thick, which is cherty and contains a fauna similar to that of the Menard formation farther west. If this bed is equivalent to the basal Menard, both the Vienna and Waltersburg formations are absent in this region. The shaly beds that intervene between the Tar Springs and Wickcliff sandstones in southwestern Indiana may be the equivalent of either the Vienna formation or the middle shaly portion of the Tar Springs sandstone as recognized in southern Illinois and western Kentucky. If the latter correlation be correct, the Wickcliff sandstone is the upper massive portion of the Tar Springs formation of that region.[21]

[21] Malott correlates the shale interval and the Wickcliff sandstone with the Vienna and Waltersburg formations, respectively, but Sutton has not certainly recognized either of the latter formations in Breckenridge and Ohio counties, Kentucky.

Waltersburg sandstone.—This formation, which is named from Waltersburg in Pope County, Illinois, is the thinnest, most shaly, and, excepting the Aux Vases, the most restricted sandstone of the Chester series. It is massive only in the vicinity of its type locality and also locally east of Marion in Crittenden County, Kentucky, at which places it resembles the Cypress sandstone. Elsewhere it consists of dark shale with thin interbedded sandstone strata which are generally dark-colored and carbonaceous where fresh and are characteristically cut by two sets of joints into long narrow pieces resembling stovewood. The sandy layers thin to the east and are absent in northwestern Christian County, Kentucky, beyond which the Waltersburg formation has not been recognized. This formation is probably locally represented in Randolph County, Illinois, by discontinuous sandstone at the top of the Baldwin formation.

The resistant Wickcliff sandstone of southwestern Indiana, which is persistent from Perry County to Patoka River, has been correlated with the Waltersburg formation by Malott, but more probably it is equivalent to the upper massive beds of the Tar Springs sandstone.

A thin coal is persistent between the Waltersburg and Menard formations in Johnson, Pope, and Hardin counties, Illinois.

Baldwin formation.—The name Baldwin formation is introduced for strata of upper Chester age in Randolph County, Illinois, that were formerly included in the Okaw formation and have been previously termed upper Okaw or Plum Creek beds of the Okaw formation. The name is derived from a town east of Kaskaskia River, south of which these strata are well exposed. On the accompanying areal map (Fig. 4) this formation has not been differentiated from the Okaw limestone and is included with the middle Chester group.

The Baldwin formation is generally from 60 to 75 feet thick and consists principally of shaly strata. Arenaceous beds, locally grading into sandstone, occur at bottom and top and represent the Tar Springs and Waltersburg sandstones of the standard Chester section. The Tar Springs member is best developed in the vicinity of Chester where it appears to succeed the Okaw limestone unconformably. The Waltersburg member achieves its greatest development farther north where it locally exhibits the jointing so characteristic of this sandstone elsewhere. Dark gray fine-grained limestone with more or less black chert occurs in one or more layers in the middle part of the formation and represents the Vienna limestone of the Ohio Valley. Although all three of these formations are undoubtedly present in the Baldwin, their development is not consistent and they can not be satisfactorily separated.

Menard limestone.—The Menard formation, which is named from Menard in Randolph County, Illinois, is one of the most uniform formations of the Chester series. It consists mainly of limestone with minor amounts of interbedded shale, although shaly zones occur locally at the base, in the middle, and at the top of the formation. It is not as cherty as the Vienna formation. In Christian County, Kentucky, the Menard formation can not be distinguished in the limestone-shale sequence between the Tar Springs and Palestine sandstones because the Waltersburg sandstone is absent.[22] Farther east the limestone in this interval is largely replaced by shale and the Menard formation has not been differentiated. It reappears in Ohio and Breckenridge counties, where it consists of two persistent dense slabby limestones separated by shale whose top is about 170 feet above the top of the Glen Dean and 95 feet below the bottom of the Kinkaid.

In southwestern Indiana the Menard formation may be represented by the Siberia limestone and the underlying and overlying shale intervals. The Siberia limestone is commonly a single ledge which is coarsely crystalline and cross-bedded and differs from most other thin limestones in the Elvira group of this region by being abundantly fossiliferous. Below the Siberia limestone and separated from it by a few feet of shale is a thin persistent layer of yellowish commonly fossiliferous limestone.

Palestine sandstone.—The Palestine formation, which is named from Palestine Township of Randolph County, Illinois, is the most persistently thin-bedded sandstone of the Chester series excepting the Waltersburg formation. It is generally thin-bedded and flaggy and contains much sandy shale. More massive beds occur locally, as near Glen Dale in Pope County, Illinois, and in northern Christian County, Kentucky. Within a short distance beyond the latter locality the formation becomes shaly and loses its identity in the Leitchfield shale. A thin coal locally occurs at the top of the Palestine sandstone in Jackson and Hardin counties, Illinois.

The Palestine sandstone also occurs in Breckenridge County, Kentucky, on the eastern border of the Eastern Interior basin, where it is locally nearly as thick and massive as the Tar Springs sandstone. In southwestern Indiana it is probably represented by the thin Bristow sandstone.

Clore formation.—Throughout its extent the Clore formation,

[22] A new name might be proposed for this limestone-shale interval, but it would be applicable in only a very small area and the writers prefer the hyphenated term Vienna-Menard because it indicates the exact stratigraphic equivalence of these beds to the formations of the standard section.

named from Clore School near Chester in Randolph County, Illinois, is mainly shale, and consequently good exposures are rare. Limestone beds, which are generally most abundant in the upper part but locally constitute nearly the whole formation, are fine-grained and dark-colored like the other limestones of the Elvira group.

The Clore has been recognized as a distinct formation as far east as central Christian County, Kentucky. Farther east the overlying Degonia sandstone is not distinguishable and the beds from the base of the Clore to the top of the Chester constitute one of the thickest limestone sections of the Chester series in the Eastern Interior basin. This consists of 250–300 feet of light to dark gray or locally bluish limestone with lenticular shale and sandstone strata and some chert.[23] East of Logan County, Kentucky, this part of the geologic column becomes predominantly shale and the Clore formation has not been differentiated from the remainder of the Elvira group. In Indiana the Clore is known as the Gennet Creek formation and consists of 10–35 feet of predominantly shaly beds.

Degonia sandstone.—The highest sandstone formation in the Chester series is named from Degonia Creek which separates Jackson and Randolph counties, Illinois. It is thickest at its type locality and thins progressively to the east. In Jackson and Union counties, Illinois, massive beds in the middle and upper parts of the formation produce cliffs and closely resemble the Pennsylvanian sandstones of this region, but in Johnson and Pope counties, Illinois, the Degonia consists of thinner and more shaly strata. In western Kentucky it is nowhere a prominent formation. In eastern Crittenden, northeastern Caldwell, and northern Christian counties the Degonia formation is a rather inconspicuous sandy horizon and farther east it completely loses its identity.

The Degonia formation occurs intermittently along the eastern side of the Eastern Interior basin in Kentucky as a thin sandstone with a maximum thickness of about 18 feet. In southwestern Indiana it is probably represented by the Mt. Pleasant sandstone, named from a town in Perry County. This sandstone is hard and even quartzitic in places but is locally interlaminated with shale and at some localities grades into sandy limestone breccia.

Kinkaid limestone.—The youngest formation of the Chester series is named from Kinkaid Creek in Jackson County, Illinois. It is one of

[23] A new name might be proposed for this limestone sequence but it would be applicable in only a very small area and the writers prefer the hyphenated term Clore-Kinkaid formation because it indicates the exact stratigraphic equivalence of these beds with the formations of the standard section.

the more uniformly developed formations and consists mainly of limestone with minor amounts of shale which increase to the east. The limestone, which is fine-grained and dark-colored, closely resembles similar beds in the Menard formation. Chert is locally abundant, particularly in the upper part, and a chert layer that may be 5 or more feet thick occurs in the lower part of the formation and persists across most of southern Illinois and into western Kentucky. Some of the Kinkaid chert is lighter colored than that of the Menard. Reddish and olive-green shales are present in the lower part of the Kinkaid formation in Johnson and Pope counties, Illinois, and Crittenden County, Kentucky, and local sandy layers appear in both the lower and upper parts, particularly in the east. Considerable shale is present locally in this formation in northern Christian County, Kentucky, but to the east as far as Logan County it is mainly limestone, and because the Degonia sandstone can not be identified in this region the Kinkaid and Clore formations have not been distinguished. Farther east the Kinkaid formation becomes very shaly and has not been differentiated.

In southwestern Indiana the Negli Creek limestone, which occurs at the top of the Chester section, and the underlying shale are probably the equivalent of the Kinkaid formation. The limestone, which is named from Negli Creek in Perry County, is massive and fossiliferous and continues as a recognizable unit into Hancock and Ohio counties, Kentucky.

Leitchfield formation.—The thick shale which constitutes the Elvira group in Logan and Butler counties, Kentucky, and farther east, is known as the Leitchfield formation, named from a town in Grayson County, Kentucky. Conspicuous reddish and greenish shales occur in the lower part of this formation from Butler to Breckenridge counties, and lenticular limestones of varied character occur principally at three horizons which are probably to be correlated with the Vienna, Menard, and Kinkaid formations. In northwestern Breckenridge County, Kentucky, the upper Chester sandstones occur and extend more or less persistently into southwestern Indiana where most of the limestone formations are recognizable although represented largely by shale.

The name Buffalo Wallow has been used for all of the Chester strata above the Tar Springs sandstone in the southeastern part of the Eastern Interior basin, but as all of the formations of the Elvira group with the possible exception of the Vienna and Waltersburg can be identified at the type locality of the Buffalo Wallow in Breckenridge County, Kentucky, the name has little value.

ELVIRA PALEONTOLOGY

The faunas of the Elvira group are neither so well known nor so characteristic as are those of the New Design and Homberg groups. The Elvira limestones are all more or less fossiliferous but they are generally so fine-grained, dense, and siliceous that fossils sufficiently perfect for identification can be collected only with difficulty and calcareous shales or shaly limestones that have yielded such prolific faunas at several lower horizons are neither abundant nor well exposed.

The best defined fauna of the Elvira group occurs in the Menard formation and is characterized by *Pentremites fohsi*, which is only slightly smaller than *P. obesus* of the Golconda, and *Pterotocrinus menardensis*. Both of these species are confined to the lower part of the formation. *Composita subquadrata* and *Eumetria costata* are common, whereas the older species *C. trinuclea* and *E. vera* are rare or absent. The typical form of *Spirifer increbescens* is introduced. *Sulcatopinna missouriensis* first appears in the Vienna and continues into the Kinkaid but is most common and locally abundant in the Menard formation.

The Vienna fauna contains no peculiar species but may be recognized by the association of certain forms, such as *Prismopora serratula*, which is largely unknown in the higher formations, with others, such as *Sulcatopinna missouriensis*, which are almost entirely confined to the Elvira group.

The Clore fauna consists of either long-ranging Chester forms or those which occur throughout the Elvira group. The only species of particular significance is *Batostomella nitidula* which is sparingly present in the other Chester formations but is very common on the surfaces of some of the Clore limestone layers.

The Kinkaid fauna is less well known than that of any other Chester formation. Although it includes several typical Elvira species, none are known to be distinctive.

CHESTER SEDIMENTATION

The pre-Chester Mississippian formations of the upper Mississippi Valley are dominantly limestone with considerable shale and little sand. In the Chester epoch sands were widely deposited in the Eastern Interior basin and this change in sedimentation must have been occasioned by some notable change in the neighboring land areas.

Chester strata do not extend as far north as do the older Mississippian formations. It is not known how far the Chester seas extended beyond the present northern boundaries of the strata, but it is

believed that they were much more restricted than their predecessors. The northern borders of the Chester are covered by the Pennsylvanian system and therefore a direct comparison, which might throw much light upon the source of the sediments, can not be made between the developments of these formations in the northern and in southern parts of the Eastern Interior basin.

Lateral variation.—The clastic strata in the Chester series are generally thickest and coarsest in the region of southern Illinois and western Kentucky adjacent to the Ohio River. Lateral variation both to east and west is considerable and differs for each of the three Chester groups.

The Aux Vases sandstone is best developed along Mississippi River and thus differs from all other Chester sandstones except the Degonia, but unlike the Degonia it does not crop out farther east in southern Illinois and western Kentucky. The Bethel sandstone is represented near Mississippi River only by a thin cherty or arenaceous horizon and is locally absent but thickens greatly to the east and then again thins and disappears. Both the Renault and Paint Creek formations in the Mississippi River counties appear to be sublittoral deposits. They are progressively less clastic farther east and consist of a considerable thickness of very pure limestone in the southeastern part of the basin beyond the limits of the Aux Vases and Bethel sandstones.

Neither the Cypress nor the Hardinsburg sandstones are typically developed in the Mississippi River counties. The Cypress is approximately equivalent to the Ruma formation of the region but the Hardinsburg is represented only by a cherty zone in the Okaw formation, thus resembling the Bethel. The Cypress and Hardinsburg sandstones are extensively developed on the east, however, and persist to the southeastern extremity of the Eastern Interior basin far beyond the limits of all other arenaceous Chester formations.

The Golconda and Glen Dean formations consist principally of limestone and the associated shale is least abundant in the northern Mississippi River counties and in the southeastern tip of the basin, and most conspicuous in those adjacent to Ohio River.

The upper Chester formations are relatively more persistent and uniform in southern Illinois than are the lower formations, but in western Kentucky both the limestones and the sandstones grade into a single thick shale unit.

The Chester sandstones that thin and disappear along the southern margin of the Eastern Interior basin in western Kentucky reappear to the north on the eastern side of the basin near Ohio River

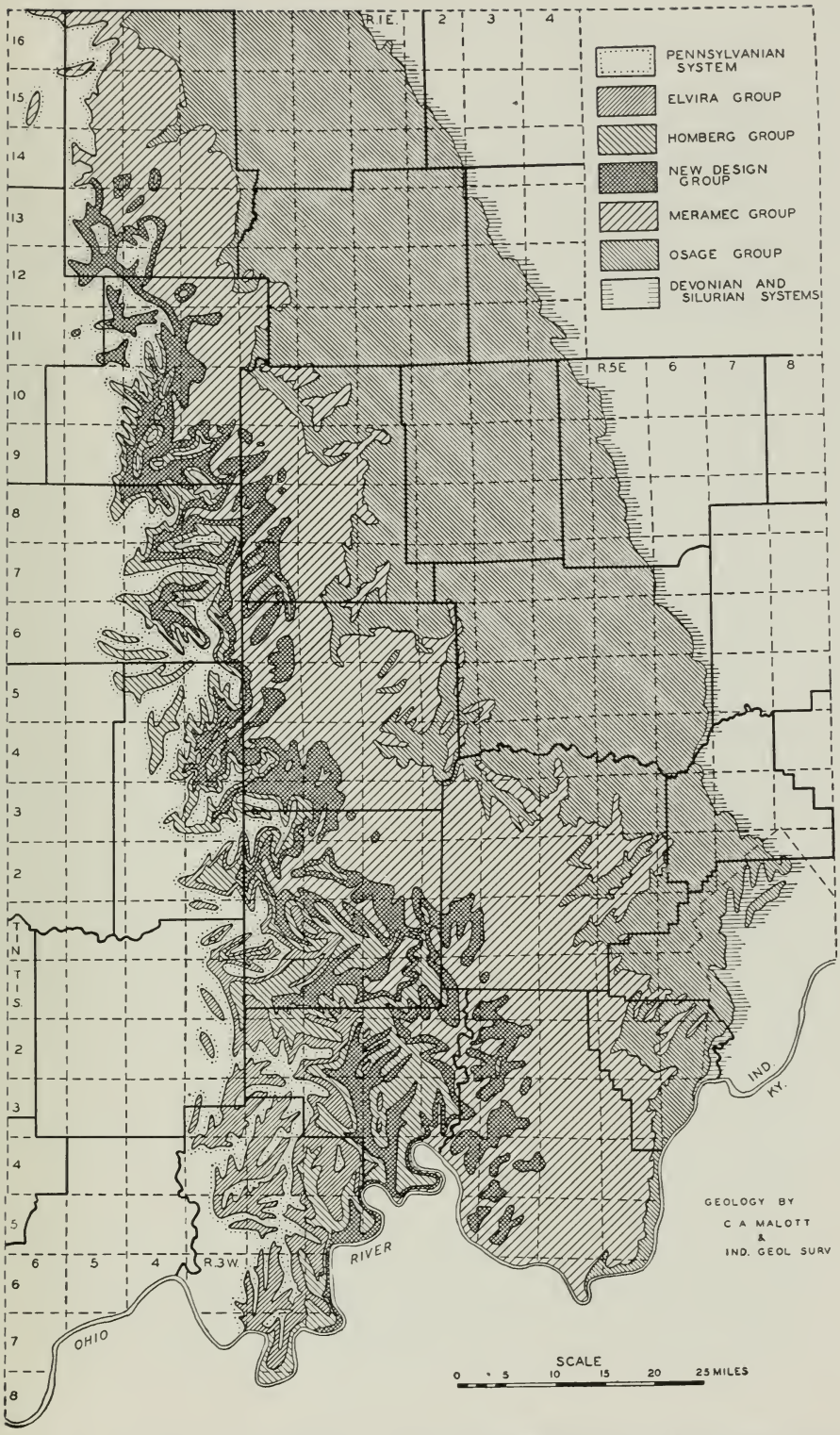

FIG. 10.—Map showing distribution of outcropping Mississippian rocks in Indiana. Areal geologic mapping under auspices of Indiana Department of Conservation, Division of Geology.

and extend northwestward into Indiana. They are not as thick in Indiana, however, as in southern Illinois and western Kentucky, and the alternating limestone-shale formations consist much more dominantly of shale than they do farther southwest.

Source of sediments.—The source of the clastic Chester sediments has not been satisfactorily determined and some of the evidence appears to be contradictory. The only conclusion that seems to be entirely justified is that the sediments which constitute the sandstone formations were not derived from the southeast because all but two of the sandstone formations are absent in the southeastern part of the Eastern Interior basin and these two are much thinner than they are farther west. On the other hand it seems likely that much of the shale in the Elvira group was contributed by a land mass on the southeast because the limestones of the group almost entirely give way to shale in this direction. If these conclusions are correct, changes in the condition of Appalachia must have occurred at the close of Homberg time, because as shown by the thick and pure limestones of the New Design and Homberg groups, no important amount of clastic sediment had been previously received by the basin from this source.

Ozarkia appears to have been land during the Chester epoch and it probably contributed sediment to the Eastern Interior basin, especially during New Design and early Homberg time. The Renault formation of Monroe County, Illinois, is distinctly sublittoral and the igneous pebbles which occur locally in its basal conglomerate may have been obtained from Ozarkia. Conspicuous redbeds occur at several different horizons in this part of the basin but are uncommon elsewhere. They are present in the Fern Glen formation and the Hoffner member of the Ste. Genevieve, and are more or less characteristic of the Renault, Paint Creek, Ruma, and Kinkaid formations. It is possible that these red sediments were derived from the residual clays formed by the weathering of the limestones and dolomites of the Ozark region. It seems impossible, however, that Ozarkia could have contributed the kind and quantity of sand that is present in the Chester sandstones. Also, all of these sandstones with the exception of the Aux Vases and Degonia are much thicker and coarser some distance east and it is evident, therefore, that another source for this material must be sought.

The introduction of arenaceous members in the New Design and Elvira groups and the reduction in thickness of the limestones in the New Design and Homberg groups northward into Indiana might be considered to indicate a northern source for the Chester sands. The various Chester formations, however, exhibit no progressive changes

along their strike from a short distance north of Ohio River to their northernmost outcrops, and except for local variations there is little change in the thicknesses of the formations or the materials of which they are composed. On the other hand, evidence of progressively off-shore conditions is given by the limestone-shale formations of the Indiana Chester as they are traced down the dip. At their most eastern outcrops from Putnam to Harrison counties these formations are represented largely by shale, and limestone layers are thin and discontinuous or entirely absent. To the west, however, the limestone layers become progressively thicker and more conspicuous to the points where they pass below drainage, and well records show still further thickening in that direction. Westward thickening of the Chester sandstones comparable to that of the limestones has not been recognized in southwestern Indiana.[24] Lateral variation, therefore, gives no indication that the sands of the Chester series were derived from the north.

Llanoria, from which much clastic material was contributed to a large basin of deposition in Arkansas and Oklahoma, is known to have been in existence as a land area in the Gulf Coastal region not only in late Mississippian but also in subsequent Pennsylvanian time. In Arkansas, the southern derivation of the Jackfork sediments, believed by some to be of upper Mississippian age, is plainly indicated by the increase in coarseness and amount of sand as the old land area is approached, and the northward direction of the currents from which the Wedington sandstone member of the Fayetteville (Chester) formation was deposited is clearly shown by the prevalent direction of cross-bedding (15, pp. 68, 115).

The Bethel, Cypress, and Hardinsburg (Hartsell as restricted by Butts) sandstones are present in the Chester section of northwestern Alabama but in the northeastern part of the state the Bethel and Cypress are absent and the Hardinsburg is much reduced in thickness (11, pp. 184, 189, 191, 192–94). It seems likely, therefore, that the Chester sands of this region were derived from Llanoria on the west.

Studies of the heavy-mineral content of several of the Chester sandstones of Indiana show close similarity of every sample, and other samples taken from the Mansfield sandstone (Pennsylvanian) of the same region contain an almost identical mineral suite. The mineralogical and physical characters of the sands point toward an original source in an area of igneous rocks and there is no evidence particularly suggesting an intermediate period of deposition. The most important characters of all these sands are: (1) a very high proportion

[24] C. A. Malott, personal communication.

of a mineral identified as leucoxene, which makes up 50–75 per cent of the heavy-mineral concentrate, and (2) a very small amount of garnet. This combination appears to exclude from consideration all known possible sources on the north and east, as highly titaniferous rocks are either absent or associated with others that are highly garnetiferous.

The evidence presented suggests that much of the clastic Chester sediment of the Eastern Interior basin may have been carried northward from Llanoria, especially as there is no evidence of any physical barrier having separated the sedimentary basin of northern Arkansas from that of southern Illinois and western Kentucky during late Paleozoic time, although it is not known that this area could have furnished sediments mineralogically similar to the Chester sands (36). Unfortunately neither the character and thickness of the Chester succession in northeastern Arkansas nor the faunas preserved in its several fossiliferous members are favorable to such a conclusion. The notable alternation of sandstone and limestone-shale units in the Chester series in southern Illinois and western Kentucky is lacking in the Chester of northern Arkansas, where its complete thickness near Batesville is less than half of that in the lower Ohio Valley. Moreover, the faunas of the Arkansas formations, although including several characteristic Chester species, possess a very different general aspect and apparently lack most of the useful guide fossils of the standard section, so that only general correlations are possible between these two regions.

It seems probable that a single land area furnished the greater part of the coarser clastic Chester sediments of the Eastern Interior basin, although some coarse and much fine material was undoubtedly brought into the basin from other directions. Because of the unsatisfactory and somewhat contradictory character of the evidence, the problem of the origin of the Chester sediments remains unsolved. Perhaps more careful studies in other regions or a more detailed knowledge of the subsurface stratigraphy of the Chester series in Illinois may furnish the solution to this problem.

Sedimentary environments.—The abundance of fossils in the limestones and calcareous shales of the Chester series attests the marine origin of these sediments and because of their intimate association there is little doubt that the non-calcareous shales were also deposited under marine conditions. The variability of these beds both laterally and vertically is proof that the Chester seas were shallow.

The Chester sandstones are similar in many respects to the overlying Pennsylvanian sandstones for which they have been mistaken

repeatedly. That they were deposited in shallow water is shown by the cross-bedding, by ripple-marked surfaces, by layers of clay-pebble conglomerate, and by locally abundant vegetable remains. The stems of *Lepidodendron* and other Carboniferous plants, which are generally preserved as casts, might have floated considerable distances from shore, but delicate and well-preserved leaves could not have been transported far. Thin coal beds are associated with the Chester sandstone formations at eight different horizons and several of these that are extensive over many square miles are almost certain evidence of terrestrial conditions. However, at a few localities, the occurrence of marine fossils preserved as casts shows that portions of some of these formations are marine. The marine fossiliferous zones generally occur in the lower and upper parts of the sandstone formations and suggest that after a period of limestone-shale deposition there remained local and shallow marine bays or estuaries which were filled with sand, and also that sand was deposited or reworked by the readvancing marine waters of the next limestone-shale period. The rare presence of marine fossiliferous zones in other parts of the sandstone formations, as in the middle of the Cypress sandstone of Christian County, Kentucky, proves that other parts of these formations also may be marine. It is probable, however, that considerable parts of the Chester sandstones are alluvial deposits laid down on a broad coastal plain.

Cycles of sedimentation.—A striking feature of the Chester series is the alternation of sandstone and limestone-shale formations. These formations may be paired to form units consisting of a lower sandstone formation probably largely continental in origin and an upper marine limestone-shale formation. Eight of these units occur in the Chester series in Illinois and ten in Indiana, and each represents a cycle of sedimentation. In four or five of the units thin coal beds are present between the sandstone and limestone-shale portions and thus these units closely resemble the cyclothems of the Pennsylvanian system.[25]

PRE-PENNSYLVANIAN UNCONFORMITY

A marked unconformity occurs at the base of the Pennsylvanian system in the central United States. In the southern, eastern and central parts of the Eastern Interior basin Pottsville beds rest on Chester formations, but in the northern and western parts of the basin the Pennsylvanian system overlaps successively older formations until in LaSalle County, Illinois, it lies on the lower part of the St. Peter sandstone (Ordovician), a horizon which occurs at least

[25] J. M. Weller, "Cyclical Sedimentation of the Pennsylvanian Period and Its Significance," *Jour. Geol.*, Vol. 38, (1930), p. 101.

5,000 feet below the base of the Pennsylvanian in the southern part of the state. It does not follow, however, that any such thickness of strata was removed from north-central Illinois by post-Mississippian, pre-Pennsylvanian erosion, because (1) most of the Paleozoic formations thin considerably to the north in this region, and (2) several important intervals of emergence and erosion occurred during the Paleozoic era, with resulting unconformities the records of which have been destroyed near LaSalle and in neighboring areas.

Along the southern margin of the basin from Union County, Illinois, to Christian County, Kentucky, Pennsylvanian beds generally rest on a variable thickness of the Kinkaid limestone, but locally, as near Alto Pass in Union County, Illinois, where the Pennsylvanian overlaps on formations as low as the Menard, and in eastern Caldwell and western Christian counties, Kentucky, on formations as low as the Palestine formation, pre-Pennsylvanian erosion has removed several of the higher Chester formations. It is uncertain whether the unconformities at these places represent channels cut in the Misssissippian surface or the truncation of pre-Pennsylvanian structures.

East of Christian County, Kentucky, the Pennsylvanian system generally overlies a variable thickness of the Leitchfield formation. In eastern Edmonson County the relief of the Mississippian surface exceeds 300 feet and a channel cut into and probably through the Cypress sandstone is filled with Pottsville sediments. A succession of coarse conglomeratic deposits which overlap formations as old as the St. Louis limestone along the Taylor-Marion county line marks the probable eastward extension of this channel.

A pre-Pennsylvanian channel in northeastern Martin County, Indiana, has been cut into Chester strata to a depth of at least 140 feet through beds ranging from the Glen Dean down to the Reelsville limestone. It extends in a north-northeast direction at least to about 2 miles west of Williams in Lawrence County and in the opposite direction to McBrides Bluff on White River and probably to Shoals. It is possible that other comparable channels occur in this region.

The northward overlap of Pennsylvanian beds is well shown along both the western and the eastern margins of the Eastern Interior basin. Along the western side the Kinkaid limestone is cut out near Marys River, the Degonia sandstone near Bremen, the Clore formation near Palestine, the Palestine sandstone at Ninemile Creek southeast of Evansville, the Menard limestone between Evansville and Baldwin, the Baldwin, Okaw and Ruma formations near Red Bud, all in Randolph County, Illinois, the Paint Creek and Yankeetown

formations east of Waterloo in Monroe County, and the Renault and Aux Vases formations near the county line north of Waterloo, where the Pennsylvanian system lies on the St. Louis limestone because the Ste. Genevieve limestone is locally absent. However, a short distance north the Ste. Genevieve, Aux Vases, Renault, and Yankeetown formations reappear from beneath the Pennsylvanian and crop out in a small area extending to the Mississippi River bluffs. An outlier of Pennsylvanian in the syncline west of the Waterloo anticline is underlain by Ste. Genevieve and lower Chester formations, and another in and about St. Louis overlies the St. Louis limestone. At numerous places east of the border of the main mass of the Pennsylvanian deposits there are inliers of lower and middle Chester formations which appear to mark buried pre-Pennsylvanian hills.

Near Alton in Madison County, Illinois, the Pennsylvanian system succeeds the Ste. Genevieve formation. North to Mercer County the Pennsylvanian border is very irregular and the strata of this system rest on successively older formations. The pre-Pennsylvanian surface is irregular, having a relief of probably more than 100 feet, and is pitted with sinkholes in certain areas. The details of the geology of this district, however, are greatly obscured by a thick covering of glacial drift.

Similar overlap of Pennsylvanian strata on successively older formations occurs northward along the eastern side of the Eastern Interior basin in Indiana. The Negli Creek limestone is cut out finally in central Perry County, the Mt. Pleasant sandstone near Branchville and Bristow in the same county, the Bristow sandstone near the northern border of the county, the Siberia limestone near Schnellville and Wickcliff in DuBois and Crawford counties, the Wickcliff sandstone near Patoka River, the Tar Springs sandstone near Dover Hill and Shoals in Martin County and French Lick in Orange County, the Glen Dean limestone near Owensburg and the Hardinsburg sandstone near Cincinnati in Green County, the Golconda limestone west of Bloomington, the Cypress and Beech Creek formations near Cataract in Owen County, the Elwren sandstone at Reelsville in Putnam County, the Reelsville and Beaver Bend formations a few miles farther north, the Paoli limestone west of Greencastle, the Mitchell limestone in the northwest corner of Putnam and the southwest corner of Montgomery County, and the Warsaw limestone at Sugar Creek a few miles farther north. Because of the irregularity of the pre-Pennsylvanian surface, however, most of these formations are locally absent in small areas south of their respective limits.

STRUCTURAL HISTORY

Many of the erosional unconformities and sedimentary hiatuses separating the Paleozoic formations of the central United States indicate only periodic oscillations of the epi-continental seas produced by extraneous diastrophism and gradual but irregular subsidence of the dominant basins of sedimentation. Other unconformities definitely reveal doming, folding, and faulting in and about such dominantly positive areas as the Ozark region, the Wisconsin and Lake Superior highlands, and the Cincinnati arch, all of which existed in the Ordovician period.

Pre-Mississippian deformation.—The oldest unconformity involved in a study of the Mississippian system in the Eastern Interior basin is the one at the base of the Devonian system. Either during or at the close of Silurian time both the Ozark region and the Cincinnati arch were gently domed and all Silurian beds were eroded and other strata as old as early Ordovician were locally exposed. Comparable deformation and erosion did not occur at this time along the Kankakee arch and LaSalle anticline in north-central Illinois.

At the close of the Middle Devonian time an extensive fault zone which has maximum relative displacement of about 1,000 feet in Ste. Genevieve County, Missouri, and which may extend an unknown distance eastward beneath the cover of younger formations was developed. Erosion in the uplifted Ozark region produced a peneplain by the beginning of the Mississippian period. Comparable deformation and erosion are not known to have occurred elsewhere in or about the Eastern Interior basin.

The extensive overlap of Mississippian strata upon much older beds in the Ozark region and northern Illinois as indicated by residual cherts and boulders of Osage age was largely the result of these two periods of erosion, whose effects are also apparent in the interior of the basin in the variable interval between the "Trenton" limestone and the base of the Mississippian system. The relations of the Mississippian system to older formations were largely determined by pre-Devonian or early Devonian erosion along the Cincinnati arch, along the north flank of the Ozarks, and probably also in northern Illinois, and by late Devonian erosion on the northeast flank of the Ozarks and in southwestern Illinois. None of the minor anticlines, synclines, or other structural features of the Eastern Interior basin can be traced to Devonian deformation.

Intra-Mississippian deformation.—Comparatively slight doming of the Ozark region occurred several times during the Mississippian period. The most important is indicated by the unconformity separat-

ing the Kinderhook series and the Osage group, which was followed by the great overlap of Osage on Ordovician beds. The Waterloo and Valmeyer anticlines were probably initiated at this time. Minor doming probably resulted in the unconformites in the Keokuk and between the St. Louis and Ste. Genevieve limestones in Ste. Genevieve County, Missouri. Doming of the Ozark region again occurred in the interval that separated Ste. Genevieve and Chester time, when the Waterloo and probably also the Valmeyer anticlines were greatly accentuated. Further minor doming of this same area led to the unconformity separating the Aux Vases and Renault formations in Monroe County, Illinois, and the overlap of the latter on lower Mississippian beds. Later minor movements were probably responsible for the local absence of several of the higher Chester formations along the southwestern margin of the basin in Missouri and Illinois. None of the other positive areas that bound the Eastern Interior basin give evidence of doming during the Mississippian period. All of the other Mississippian unconformites are apparently related simply to temporary emergent conditions.

Post-Mississippian deformations.—At the close of the Mississippian period the positive areas surrounding the Eastern Interior basin were all domed and subjected to erosion. Older structures, such as the Waterloo anticline, were accentuated and new structures, such as the LaSalle anticline and the Cap-au-Gres fault and flexure zone, were formed. Normal faulting on a small scale occurred in Union County, Illinois, and Hart County, Kentucky (10).

By middle Pottsville time, when Pennsylvanian sediments were first extensively deposited in the Eastern Interior basin, erosion had nearly peneplained this region and the Pennsylvanian overlapped Ordovician beds to the north. During the Pennsylvanian period the basin continued to subside progressively but not uniformly in response to loading, and some of the existing structures, notably the LaSalle anticline, were gradually accentuated.

Some time after the close of the Pennsylvanian period the Ozark region and the Cincinnati arch were again uplifted and domed to a greater extent than ever before and additional movement occurred along the LaSalle anticline, the Cap-au-Gres fault and flexure zone, and the Waterloo anticline. A great uplift with complicated faulting extending from beyond Ste. Genevieve County, Missouri, to at least Hart County, Kentucky, and the development of Hicks dome occurred in the southern part of the basin and the present southern boundary of the basin was formed.

An extended period of erosion followed, reducing the region to a

peneplain which was later warped and overlapped at the south by the Mississippi embayment deposits of late Cretaceous age. During Cenozoic time several slight regional warpings and changes in level occurred, and the southern part of the basin is not yet in complete equilibrium as indicated by earthquakes (of which the New Madrid disturbance in 1811 was an outstanding example), one or more tremors being experienced each year.

Nature of faulting.—The complex faulted area in the southern part of the Eastern Interior basin is remarkable in that it exists in the midst of a great region of nearly horizontal and undisturbed rocks. The faulting is generally considered to be the "normal" type but it is peculiar in several respects. Faults, some notably sinuous and all with high-angle fault planes, with some of which steeply dipping and even overturned beds are associated, occur in the fault zone extending from Ste. Genevieve County, Missouri, to Union County, Illinois, and in the Shawneetown-Rough Creek zone in southeastern Illinois and western Kentucky where locally the displacement is as great as and possibly much more than 3,500 feet (10, p 59). Formations stratigraphically much lower than those extensively exposed near by are brought to the surface at a number of places. Faults of this type seem to have resulted from compressive rather than tensional stresses and are therefore probably high-angle thrust faults.

Another type of faulting with maximum displacements locally as great as 2,000 feet (94, p. 100) is excellently developed in the fluorspar district where a complicated mosaic pattern has resulted from the intersection of numerous nearly straight lines of displacement. The major faults roughly parallel each other and the blocks between them are cut by minor displacements commonly in a step-like manner. Some of the fault planes can be examined to a depth of 200–700 feet in fluorspar mines. Several of these are inclined first in one direction and then in another so that the terms "hanging-wall" and "footwall" can not be consistently applied. Slickensides indicate that movement along the faults has occurred at several different times and in several different directions, with complete reversal in some places. Most of the movements include an important horizontal component and some were nearly horizontal.

Vulcanism.—Intrusions of basic rock in the form of dikes, sills, and plugs crop out at several places in Hardin and Pope counties, Illinois, and Livingston, Crittenden, and Caldwell counties, Kentucky. Similar material has also been encountered in the fluorspar mines and in a coal mine on the northwest in Saline County, Illinois.

The association of igneous intrusions with fissure-vein deposits of

fluorspar accompanied by small amounts of argentiferous galena indicates hydrothermal mineralization and suggests that the post-Pennsylvanian uplift which now forms the southern boundary of the Eastern Interior basin resulted from a deep-seated igneous intrusion of considerable extent and that the faulting was produced by compression about the borders of the intruded mass and tension of the arched strata which it upraised. Subsequent cooling and shrinkage of the igneous material might explain the minor readjustments that continue to the present day.

OIL AND GAS FORMATIONS

Illinois.—Production of oil or gas is being or has been obtained from several horizons in the Mississippian system in Bond, Clark, Clay, Clinton, Coles, Crawford, Edwards, Fayette, Franklin, Gallatin, Hamilton, Jackson, Jasper, Jefferson, Lawrence, Marion, Morgan, Randolph, Richland, Shelby, Wabash, Washington, Wayne, and White counties. The most widely productive beds are in the lower part of the Chester series as follows.

Palestine sandstone: Wabash County.

Waltersburg sandstone: Gallatin and White counties.

Tar Springs sandstone: Wabash County; 600-foot Froemling sand of Jackson County.

Sandstone member of Golconda formation: "Gas" sand of Lawrence County.

Cypress sandstone: Edwards, Marion, and Wabash counties; Weiler sand of Clinton, Coles, Fayette, Marion, Richland, and Wabash counties; Carlyle sand of Clinton County; Kirkwood sand of Lawrence County; Bellair 900-foot sand of Crawford and Jasper counties; 800-foot Froemling sand of Jackson County, upper Lindley sand of Bond County; Sparta gas sand of Randolph County

Sandstone member of Paint Creek formation: Stray sand of Fayette County.

Bethel sandstone: White County; Benoist sand of Clinton, Fayette, Jefferson, Marion, and Wabash counties; Tracey sand of Lawrence County.

The so-called Aux Vases sand of Clay, Marion, Shelby, Wayne, and White counties and possibly the Bradley sand of Wayne County and the lower Lindley sand of Bond County are probably the subsurface equivalent of the Hoffner member of the Ste. Genevieve formation known in outcrop in Union County.

A considerable proportion of the oil produced in Illinois has been obtained from porous beds occurring at several horizons in the Meramec limestones, especially in the Ste. Genevieve formation. The latter have been commonly referred to as the McClosky "sand," actually a porous oölite. Records of the McClosky wells in Lawrence County are so incomplete that the precise position of the producing horizon, the original McClosky "sand" (and Oblong "sand" of Crawford County), in the upper part of the Ste. Genevieve formation can

not be determined. Most of the recent McClosky production of Clay, Edwards, Franklin, Jefferson, Marion, Richland, Wabash, Wayne, and White counties is obtained a short distance below the Rosiclare sandstone member, which is itself productive in Jefferson County and elsewhere in the central basin fields. The main producing "sand" of the Martinsville pool in Clark County is either in the lower part of the Ste. Genevieve or the upper part of the St. Louis limestone. A still lower horizon in the Martinsville pool and a horizon of small production recently developed in Franklin and Jefferson counties are probably in the St. Louis limestone. Small amounts of oil and gas have been obtained from the Mississippian limestone just beneath the pre-Pennsylvanian unconformity in Morgan County at either the top of the Salem or the base of the St. Louis limestone. A few wells in the Salem pool of Marion County produce from the Salem limestone. Showings from Meramec limestones have been reported in Edgar, Clark, Coles, and Cumberland counties.

The Carper sand of the Martinsville pool is the only producing formation in the Osage group. Showings at a similar horizon are reported also in the Westfield pool, and other Osage showings have been encountered in Fulton, Morgan, Schuyler, and Union counties.

Indiana.—The main producing formations in the Mississippian system of Indiana are as follows.

Tar Springs sandstone: Colvier, Davidson deep, Loveless sands
Hardinsburg sandstone: Buchanan, Hightower shallow, Hoover gas sand
Cypress sandstone:[26] Cunningham shallow, Hoover oil, Hyneman, Zimmerman sands
Elwren sandstone: Barker, Snyder shallow, Willis sands
Bethel (Sample) sandstone: Cunningham deep, Hunt, Mixon sands
Mooretown sandstone: Hightower deep, Kirkwood, Oakland City, Petersburg Snyder deep sands
Paoli limestone: Brown, Monroe City deep, Tracy, Vierling "sands"

More or less good showings have been reported from several deeper beds and the New Albany shale has yielded gas in Harrison County.

Kentucky.—In western Kentucky the main producing formations of the Mississippian are as follows.

Upper Chester sandstones: Stray sands
Tar Springs sandstones: Jett or Stevens sand
Hardinsburg sandstone: Jones sand
Cypress sandstone:[26] Jackson sand
Elwren sandstone: Barlow sand

[26] Recent subsurface studies suggest that the Cypress sandstone as identified in Indiana and in the subsurface of western Kentucky is the mid-Golconda sand known as the "Gas" sand in the Lawrence County field of Illinois (P. L. Dana and E. H. Scobey, "A Cross-Section of the Chester Series of the Illinois Basin" read before the Am. Assoc. Petrol. Geol., April 11, 1940). If this suggested correlation is correct correlations of the lower Chester producing sands in Indiana and Kentucky probably also require adjustment.

Mooretown sandstone: Bethel sand
Ste. Genevieve: McClosky "sand"
St. Louis: Major; Warren County shallow "sands"

Small amounts of oil and gas have been encountered at several depths in the Osage group in various parts of Breckenridge and Grayson counties. In Meade and Hardin counties the New Albany shale and overlying strata yield gas.

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